Hierarchical Investigation of Socioeconomic Drivers of Decadal Scale Land-Cover changes in the Upper Midwest

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Rural Population Growth

DEMOGRAPHICS

Population of Rural America Is Swelling

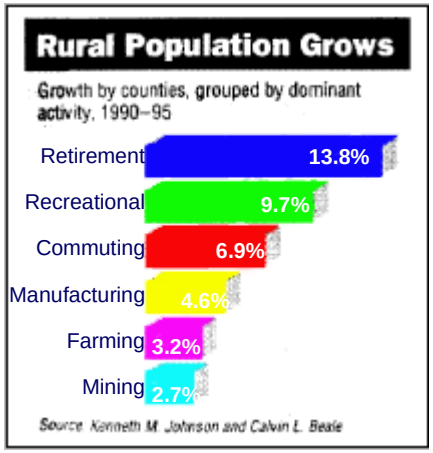
By Scott Kilman
And Robert L. Rose
Staff Reporters of The Wall Street Journal

Pat Murphy is moving his family to Algona, Iowa, from Stockton, Calif., to escape crime, expensive car insurance and slumping home values. But he's also in search of something he can't find in the city.

"In the doughnut shop, the customers are considerate enough to pour each other coffee," he says of life in northern Iowa. "You don't see that in California."

The 1990s, it turns out, are full of Pat Murphys trading in urban life for country living. At the same time, more people in rural areas are staying put. The result: Rural America is making a surprising comeback in population.

New research by two prominent rural demographers finds that most rural areas of the country are growing at their fastest rate in more than two decades. The demographers, Kenneth M. Johnson of Loyola University in Chicago and Calvin L. Beale of the U.S. Agriculture Department found



says Mr. Beale, who is credited with calling a previous rural population turnaround, when decades of migration out of rural areas were reversed in the 1970s.

Metropolitan areas, meanwhile, have had a 5.8% increase in population over the same period, still higher than the rural

South. But even places that are lagging, such as counties dependent on farming and mining, are faring far better than they did in the 1980s. And while the population turnaround in rural areas flies in the face of conventional wisdom, it doesn't surprise the people who are witnessing the comeback.

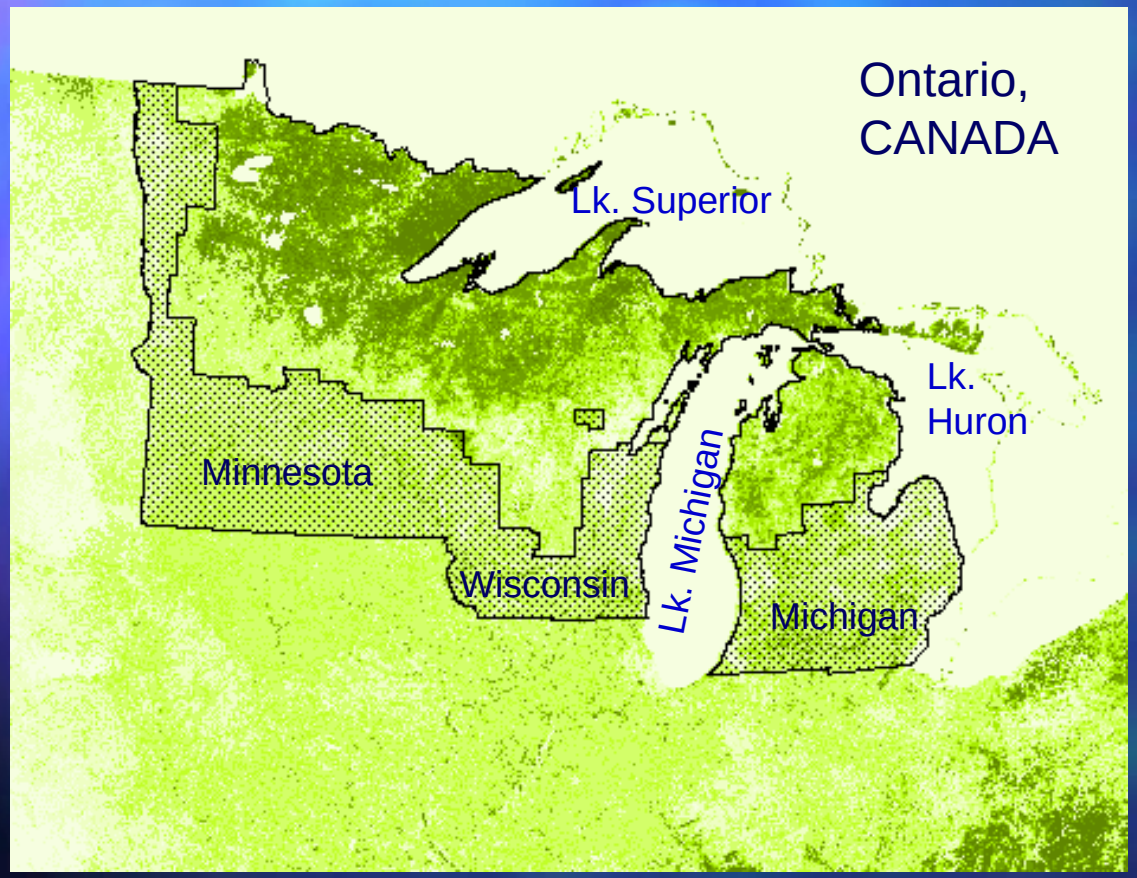
Mt. Pleasant, Iowa, grew 5.2% between 1990 and 1994 to 8,374 people. The southeastern Iowa town is in the middle of a boom in home-building. Main Street landlords are renovating second floors to accommodate the demand for retail space. "Life is a lot more peaceful here and homes are a lot cheaper," says Daniel Peterson, a local merchant and former pilot who once lived in Denver.

Others are finding they can enjoy rural life even while working for a big-city employer, either through telecommuting or long-distance commutes. The demographers found that 90% of the counties with a large portion of commuters are growing.

Jobs also appear to be drawing some city dwellers to the country. According to

Wall Street Journal

Study Area - Upper Midwest, USA



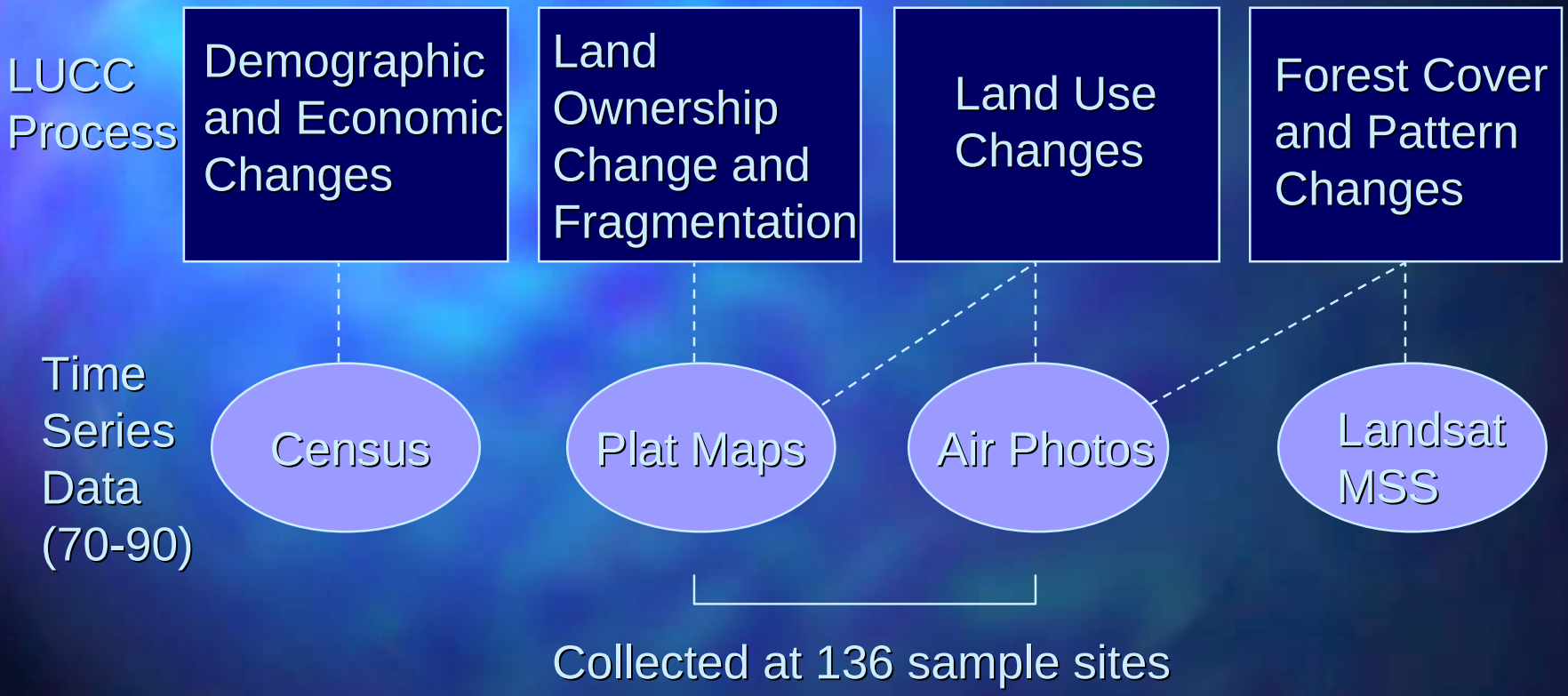
- About 2/3 forested, mostly rural
- Forest cover has been increasing per inventories
- Nearly completely deforested by 1910

Percent forest cover image from AVHRR and USFS FIA data by Zhu and Evans, 1994

Research Questions and Interim Progress

1. What were the types and rates of land cover change and fragmentation over two decades in the study region?
   - Pilot study in three county area of Michigan, methodological progress.
2. What is the sensitivity to the scale/resolution at which those changes are monitored (air photo versus MSS)?
   - Land use from air photos and fores cover from Landsat; thematic detail.
3. How are the changes and fragmentation related to changes in the fragmentation of land ownership?
   - In general, land ownership is fragmenting and forest cover is increasing, and often defragmenting, but the causal relationships require land use information.
4. What quantitative functions describe the effects of socioeconomic processes on observed rates of land cover composition and pattern change?
   - Economic, demographic, environmental, and institutional/policy factors.

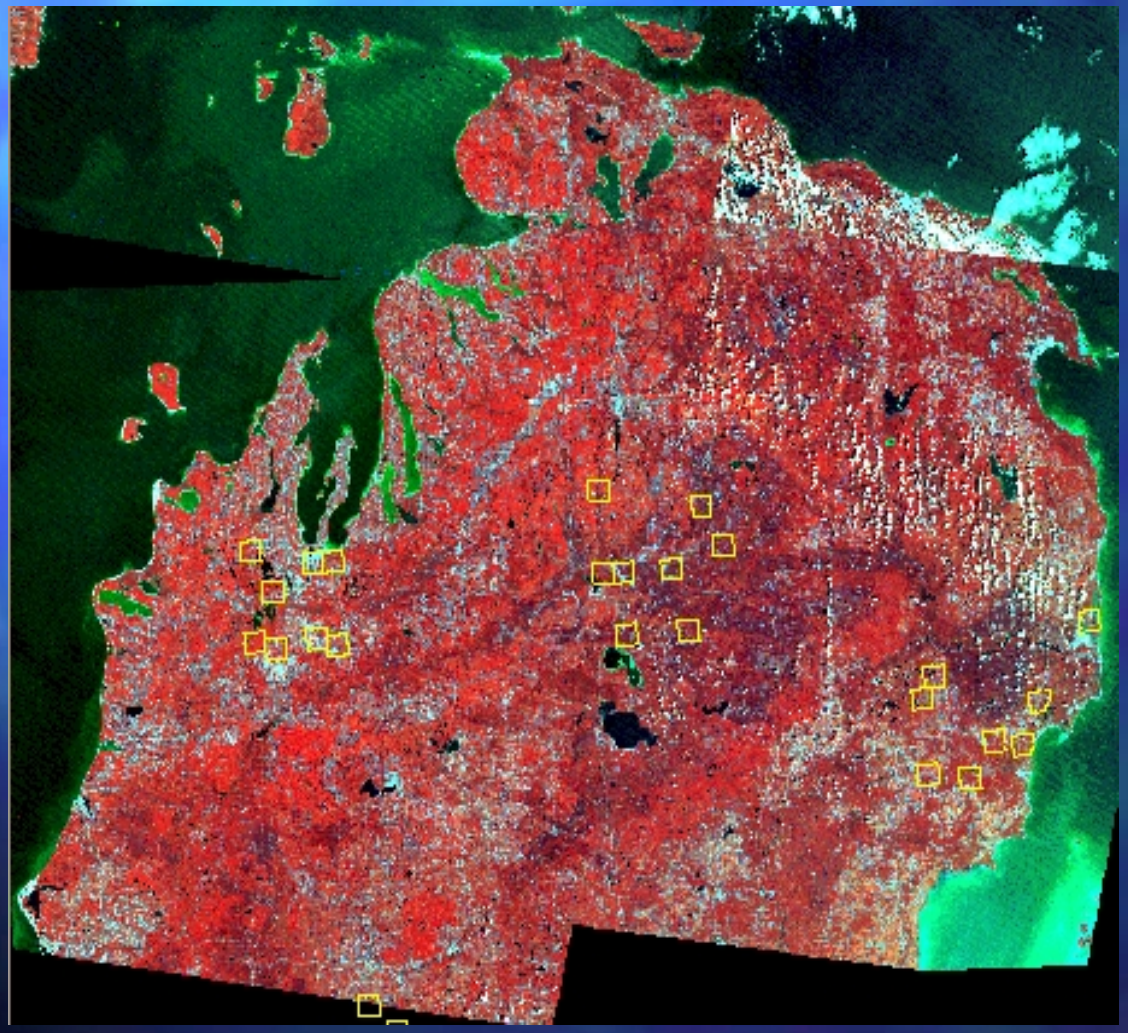
Empirical Observation of LCLUC



Methods to Date

- Forest cover and pattern mapping (NALC)
  - Pre-processing, classification, and accuracy assessment
  - Parcel fragmentation and forest cover change in three Michigan counties (S.A. Drzyzga, Master's Thesis)
  - Error in change analysis based of pattern metrics
- Land use mapping and change analysis
  - Arc/Info based tools for: (1) mapping from air photos & parcels
    (2) quality control (near complete)
- Model development
  - County-level land use estimates
  - ArcView model & GUI with stochasticity and dynamics
  - Link with SNNS for artificial neural network analysis
  - Pilot-testing calibration and validation procedures

Forest Cover Pattern and Change

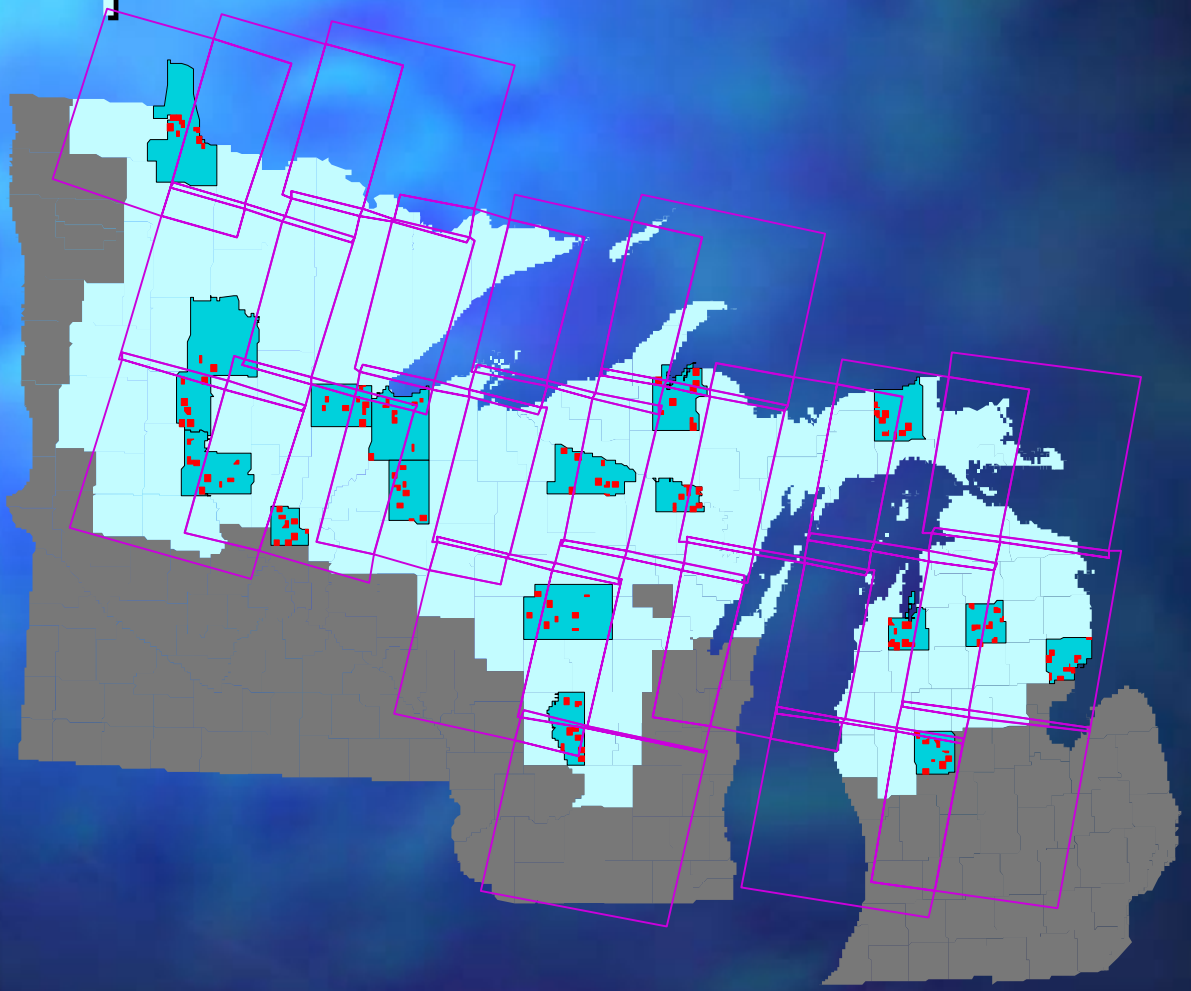


Based on North American Landscape Characterization (NALC) data.

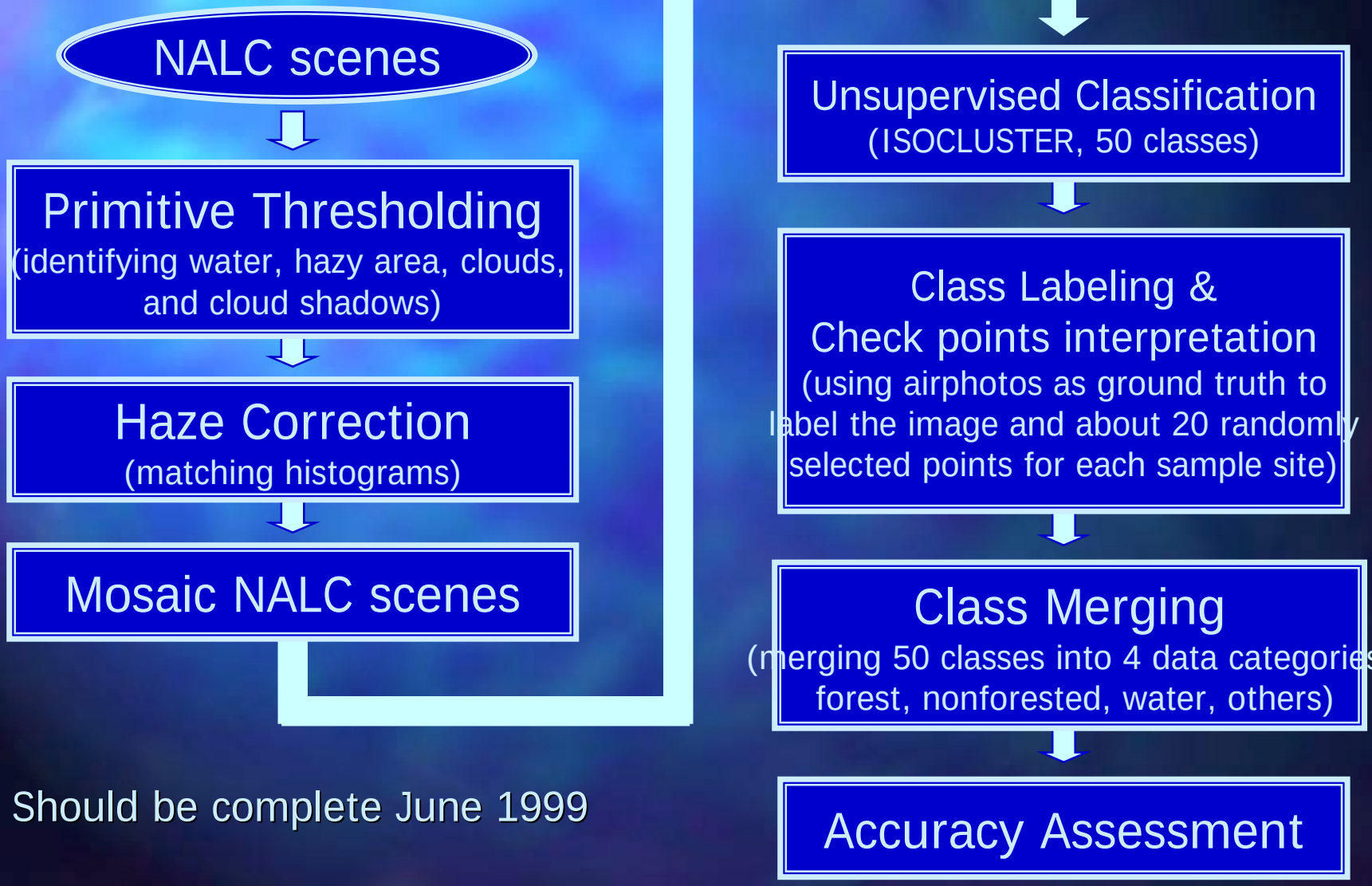
NALC Mosaic of the Northern Lower Peninsula of Michigan

1991

Locations of Landsat Scenes, Sample Counties and Sites

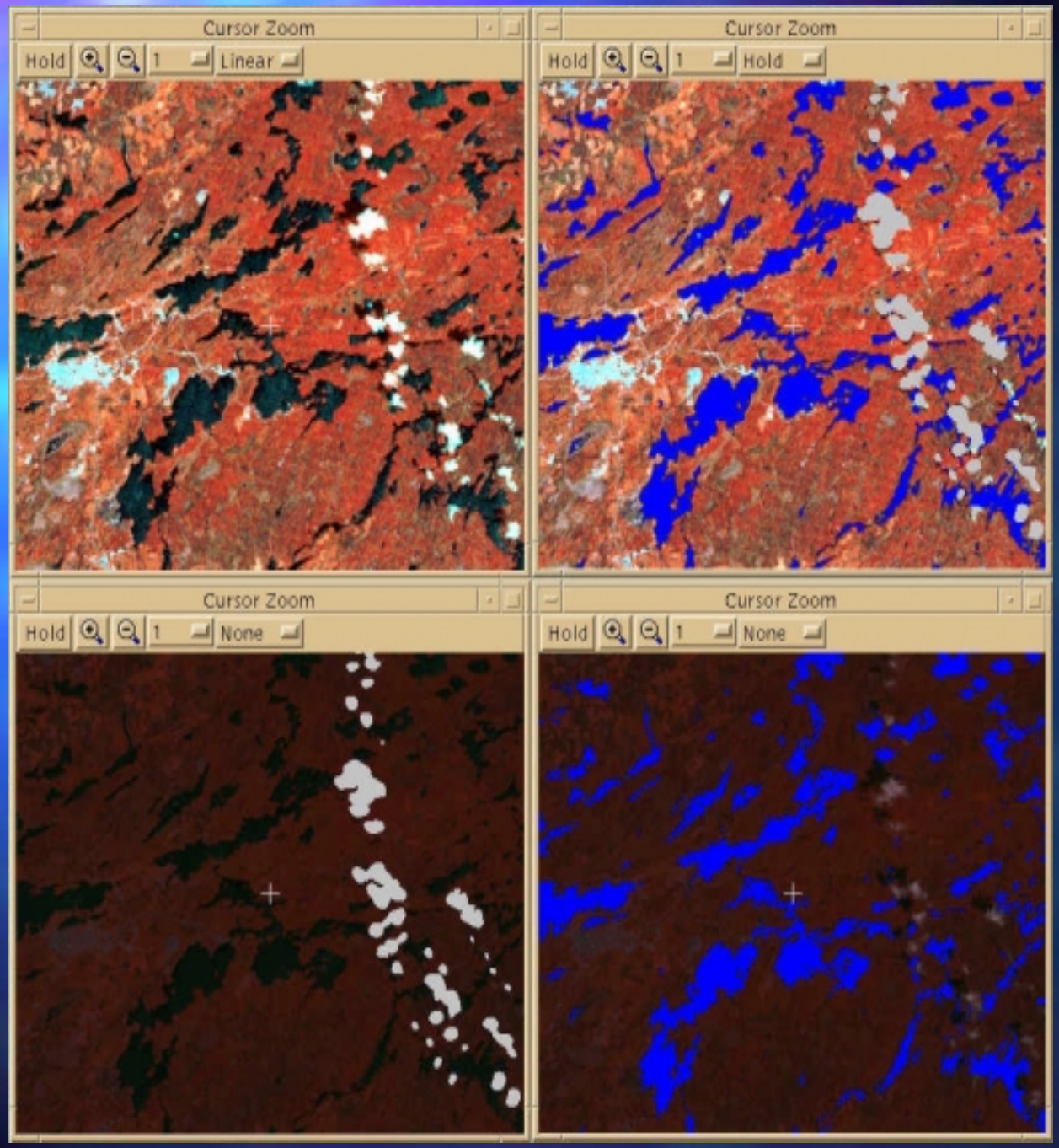


NALC Processing Procedures



Should be complete June 1999

NALC scene

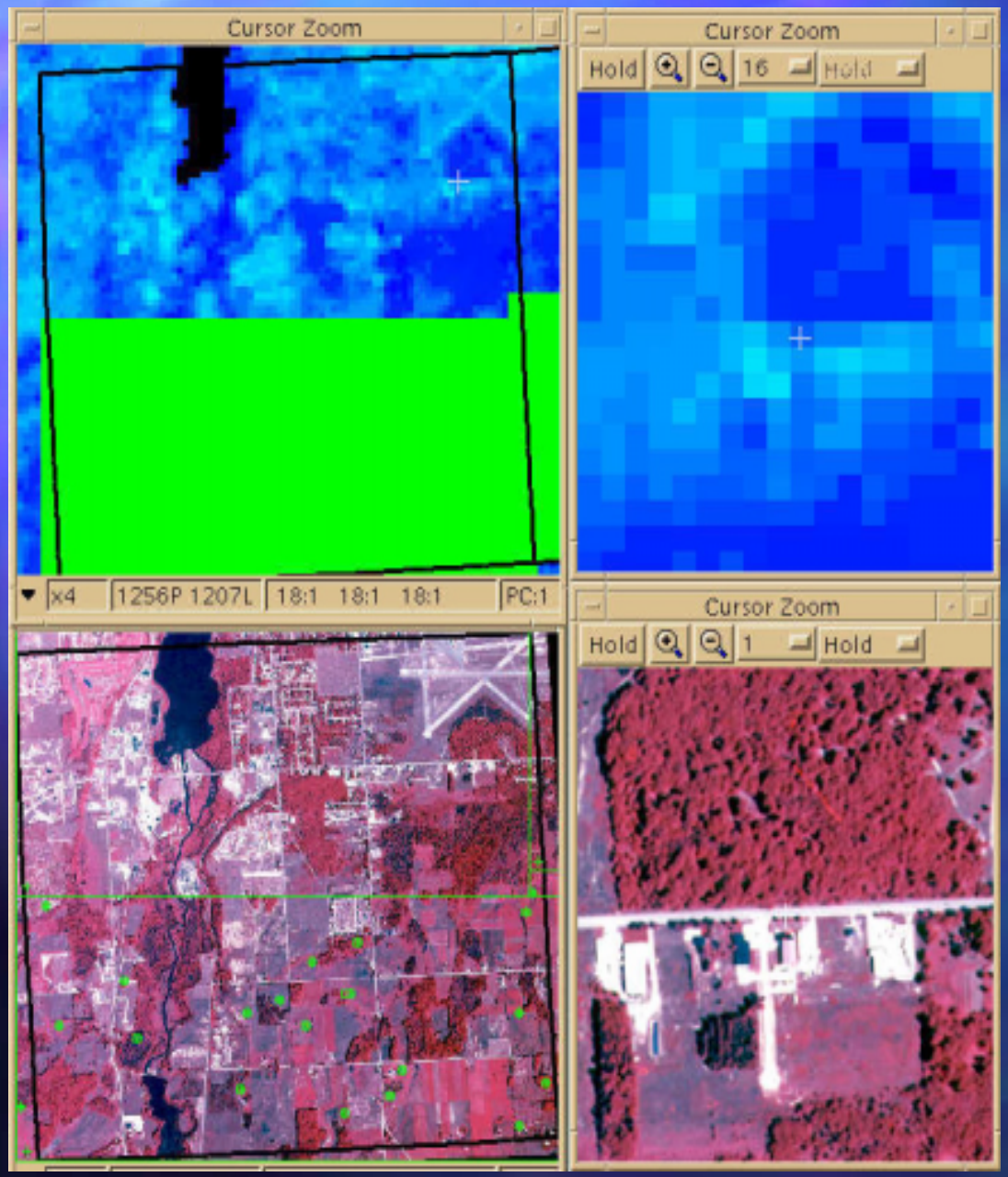


NALC scene with masks

Clouds & shadows mask

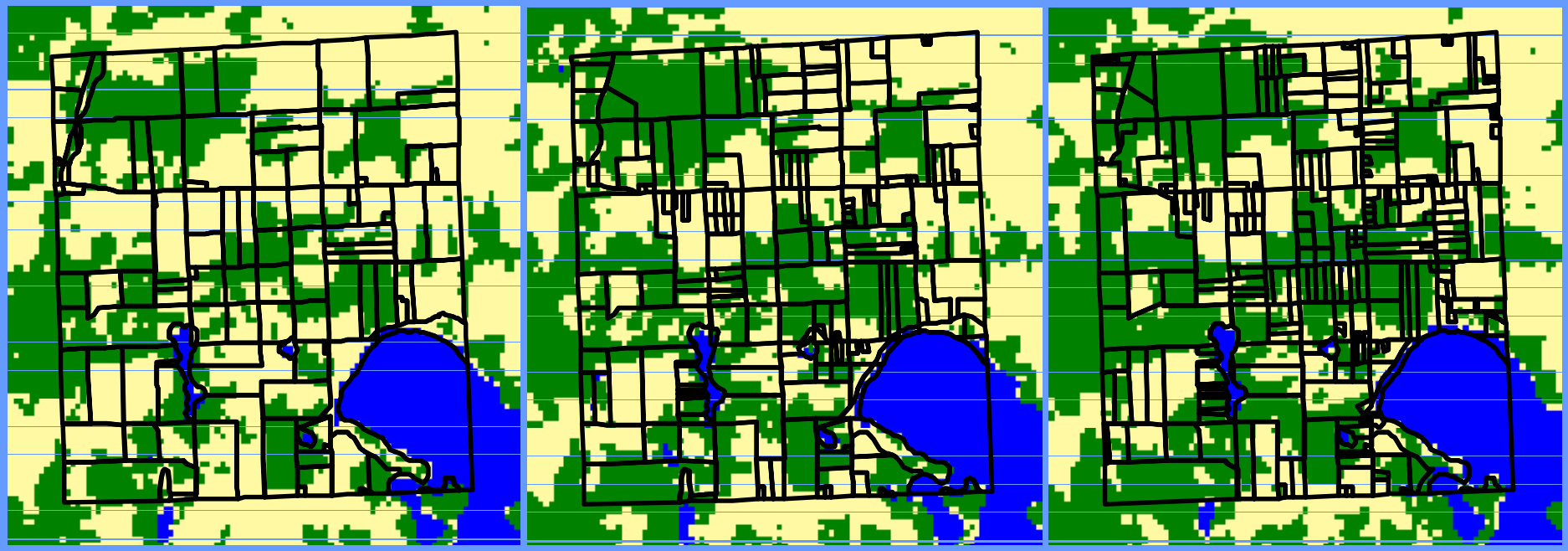
Water mask

Labeling classes by using airphoto as ground truth



Sample points for accuracy assessment (green lines depict the actual pixel size on NALC)

Forest Cover Change



1973 1985 1991

Forest Nonforested Water

Forest Fragmentation Pilot Studies

- Sample area study to quantify errors in measuring forest fragmentation dynamics.
- Small area study to test for meaningful relationships between parcel changes and forest cover change and fragmentation.

NALC Data for Change Analysis

Pre-registered Landsat MSS Scenes

60 m resolution

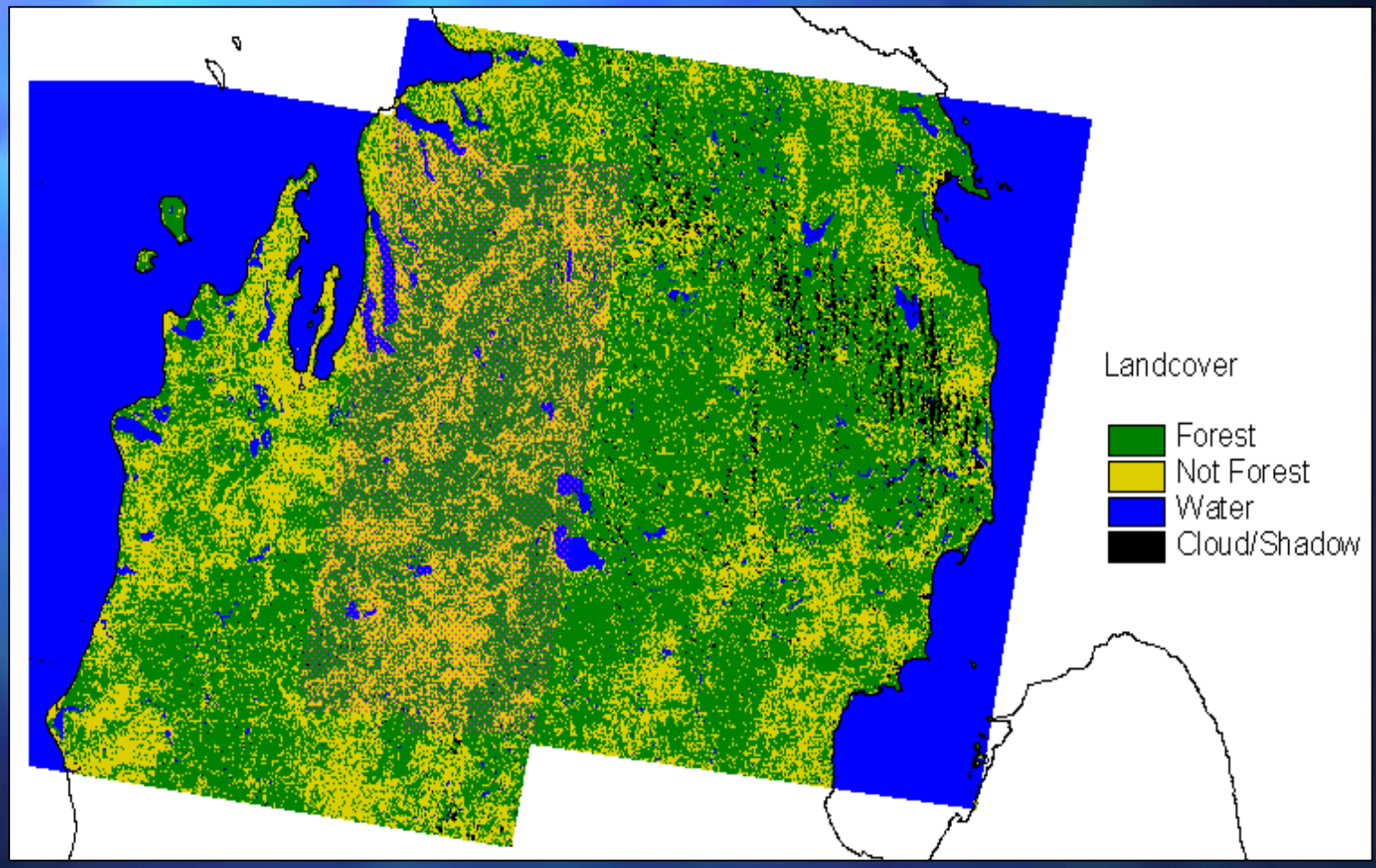
About 25 % overlap between adjacent scenes

1972-1975

1985-1987

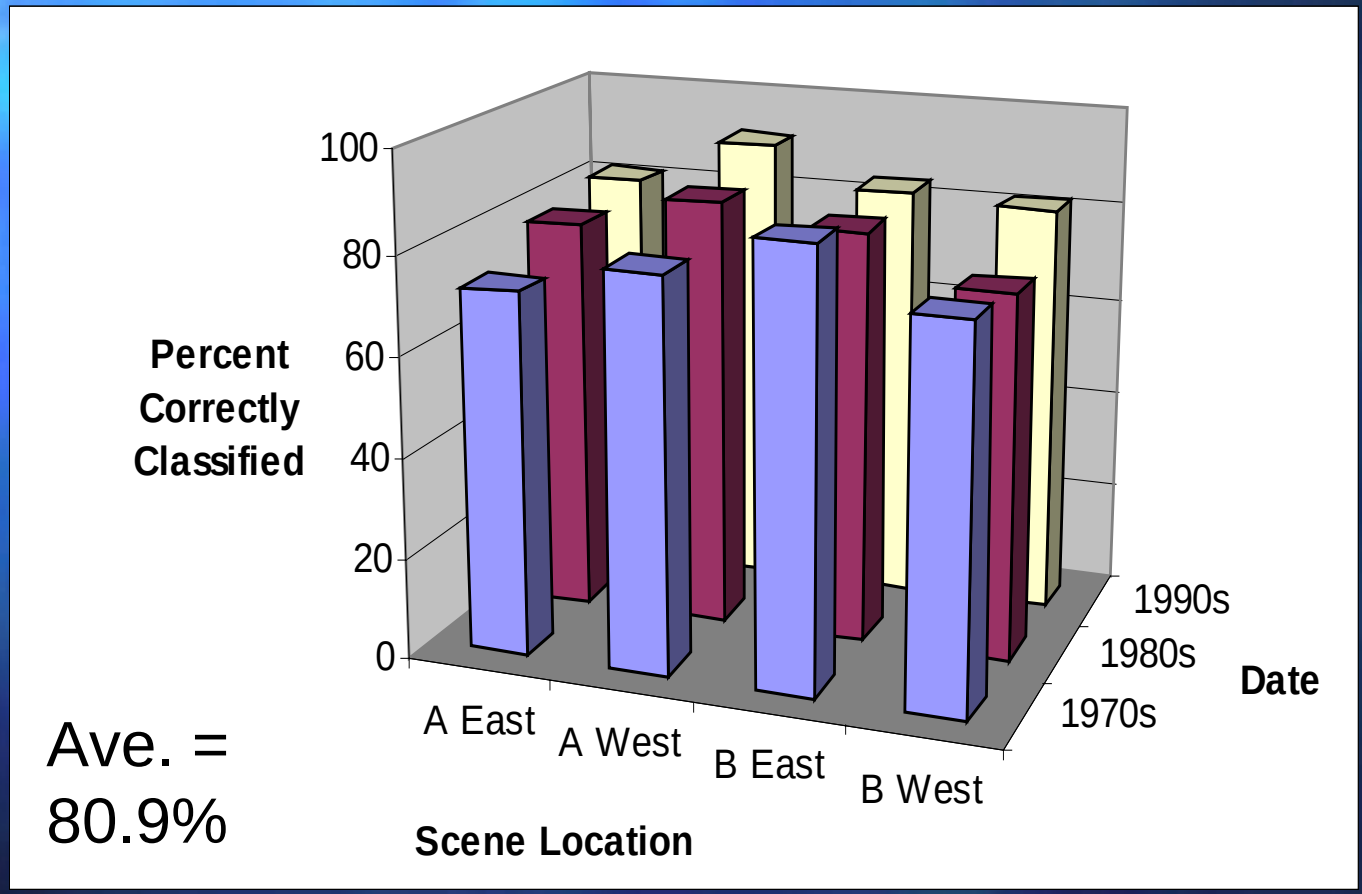
1990-1992

Classified Land Cover: Site A 1990s



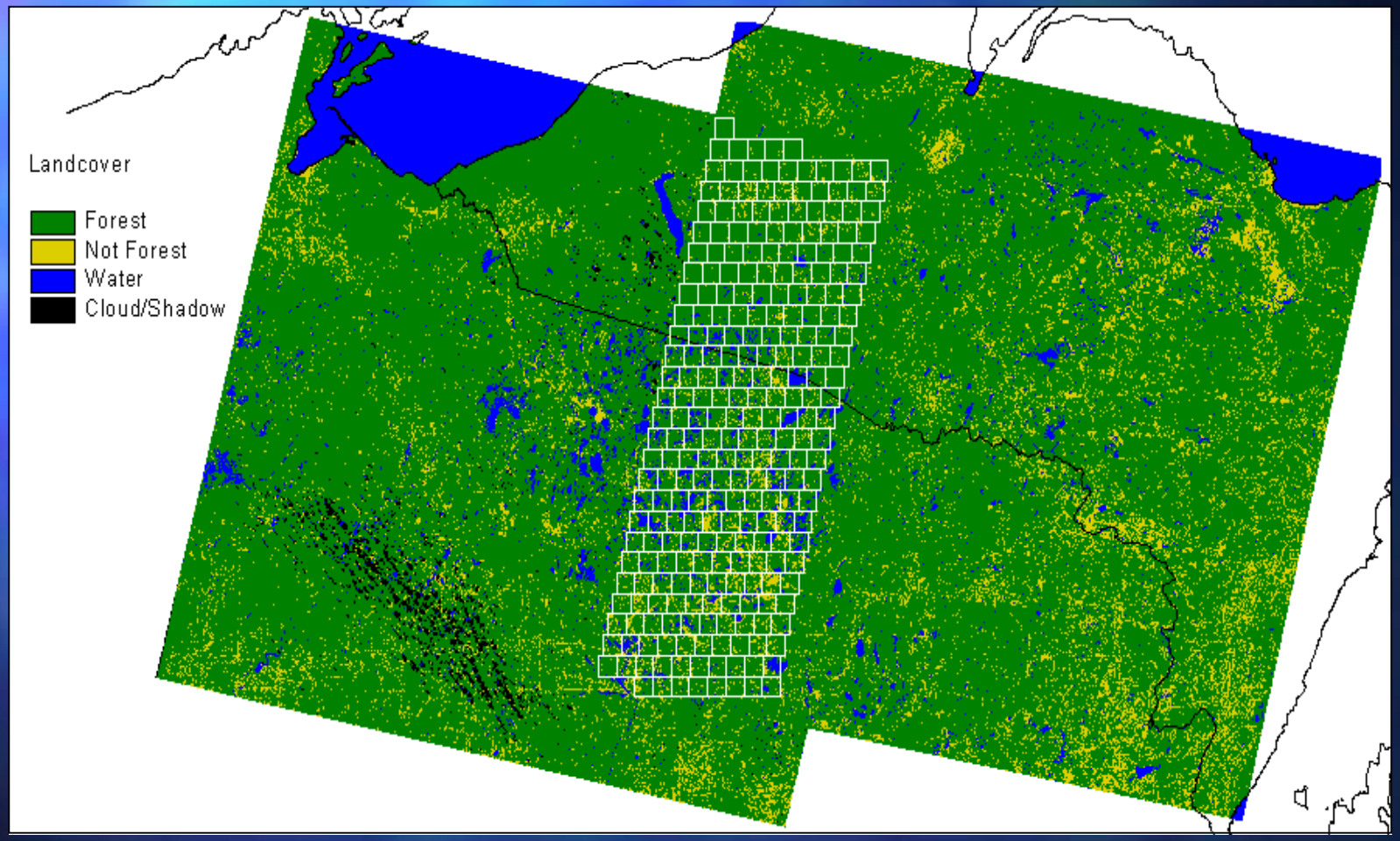
Shading indicates overlap area

Classification Accuracies



Ave. = 80.9%

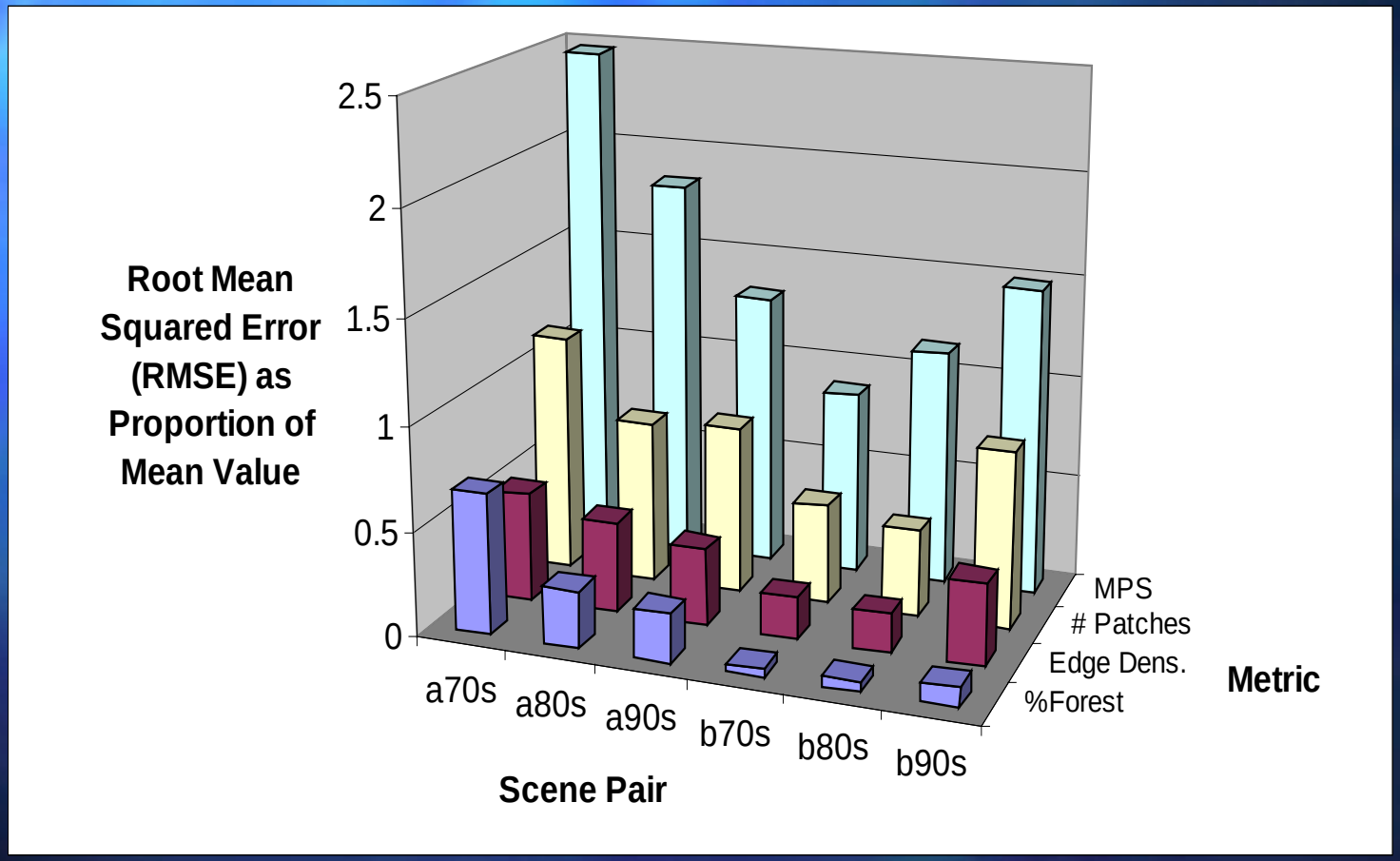
Classified Land Cover: Site B 1990s



Landscape Metrics Assessed

Metric	Abbr.	Definition
percent forest	PF	proportion of the landscape covered by forest
number of patches	NP	number of forest patches
mean patch size	MPS	average size of forest patches
edge density	ED	length of forest/non-forest edge ÷ landscape area

Summary of Errors in Image Pairs



Model of Error in Metric Differences

Hypotheses

Errors are larger where:

- forest is near parity with non-forest
- haze is more prevalent
- image pair is taken under divergent phenological conditions

Variables

- 2nd-order polynomial of ave. percent forest
- % of site with haze
- diff. in image avg. NDVI or difference in Julian date

Predicting Error in Percent Forest

Error in Percent Forest =

$-7.93 + 0.45\,(PF) - 0.005\,(PF^2) + 0.12\,(haze) + 1.99\,(diff\ NDVI)$

- F-test = 423.84 ($p > 0.99$); Adj. R^2 = 0.50

With difference in Julian Date instead of diff NDVI

$-4.87 + 0.37\,(PF) - 0.004\,(PF^2) + 0.06\,(haze) + 0.31\,(diff\ Days)$

- F-test = 284.02 ($p > 0.99$); Adj. R^2 = 0.40

all variables are significant at $p > 0.99$

Predicting Error in # of Patches

Error in Number of Patches =

$-27.00 + 2.03\,(PF) - 0.02\,(PF^2) + 0.42\,(haze) + 7.56\,(diff\ NDVI)$

- F-test = 453.23 ($p > 0.99$); Adj. R^2 = 0.51

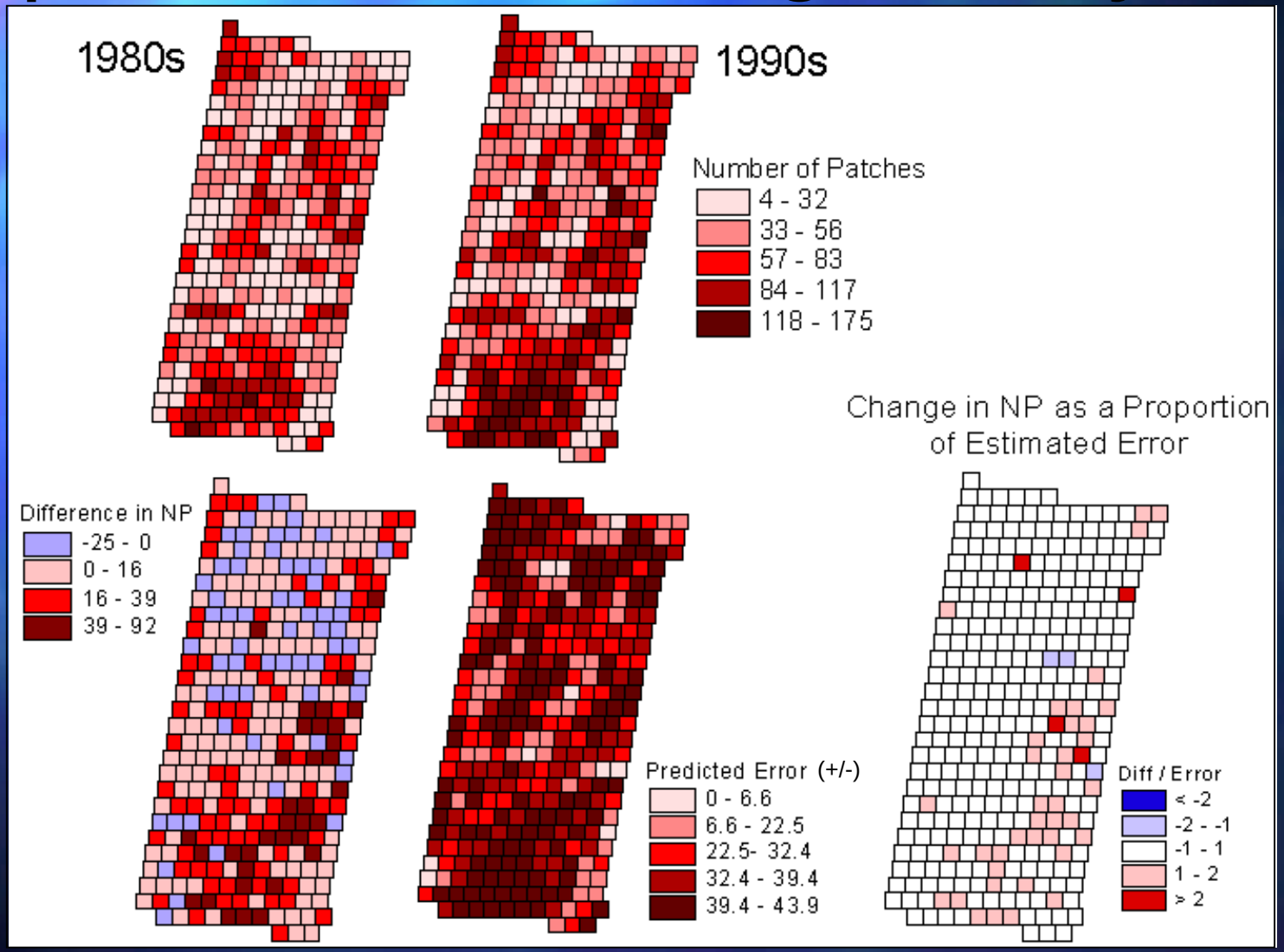
With difference in Julian Date instead of diff NDVI

$-9.85 + 1.71\,(PF) - 0.02\,(PF^2) + 2.00\,(haze) + 1.01\,(diff\ Days)$

- F-test = 307.81 ($p > 0.99$); Adj. R2 = 0.42

all variables are significant at $p > 0.99$

Application to Change Analysis



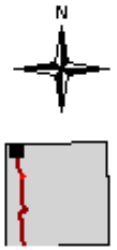
Conclusions from Pilot Study I

- Landscape metrics calculated from satellite images are subject to measurement error.
- Increasing size of landscape partitions decreases error, but map generalization through sieving or filtering has inconsistent effect on error.
- Error at a location for some metrics can be estimated using percent forest, haze, and difference in phenological condition.

Land Parcel Changes

Ownership Characteristics

Mecosta County, MI



Site Locator

County Locator

Legend

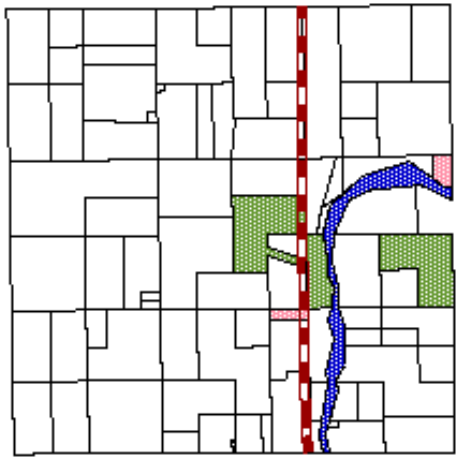
- Water Features
- Public Lands
- Small Parcels
- Parcel Boundaries
- Major Highway

Land Ownership:
Rockford Maps Publishing

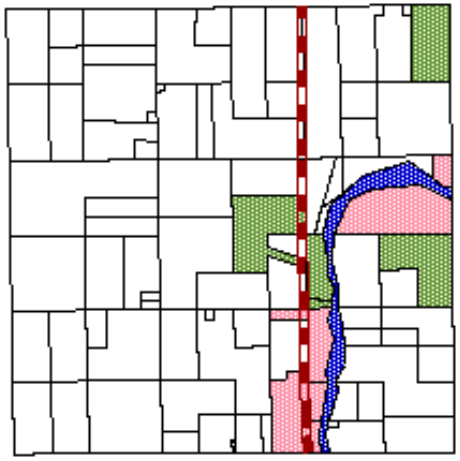
Natural Features:
USGS 1:100000 Topographic Maps

Compilation: Scott A. Drzyzga

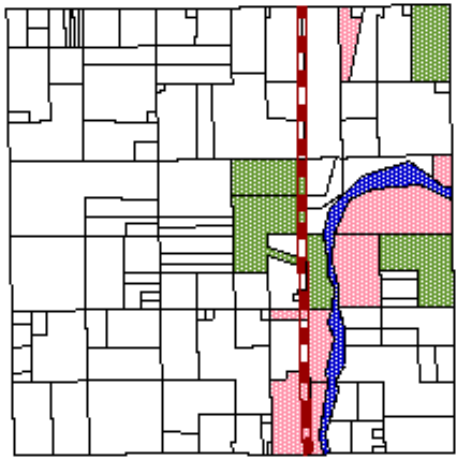
1961



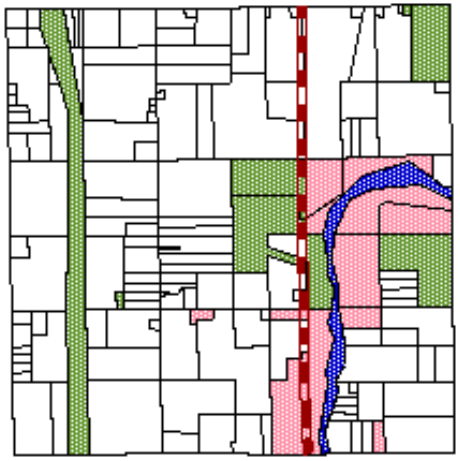
1969



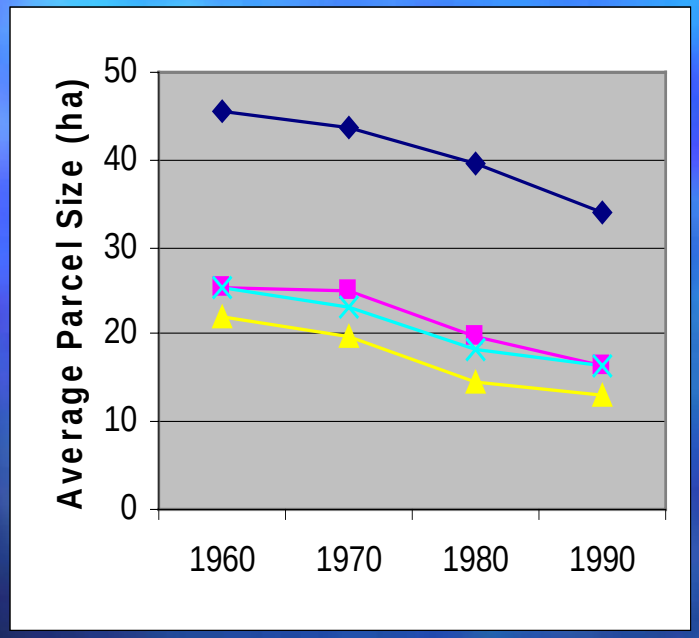
1980

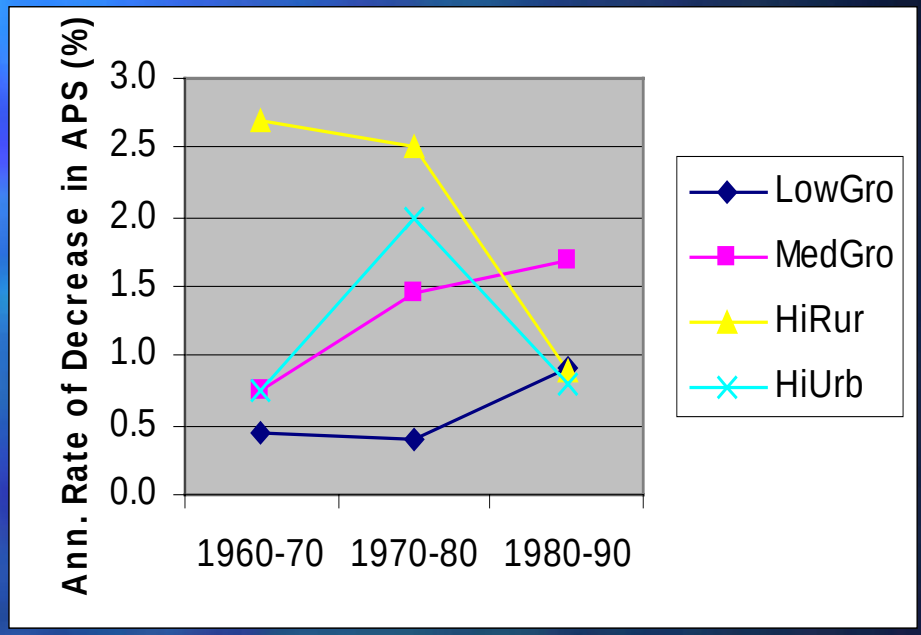


1990



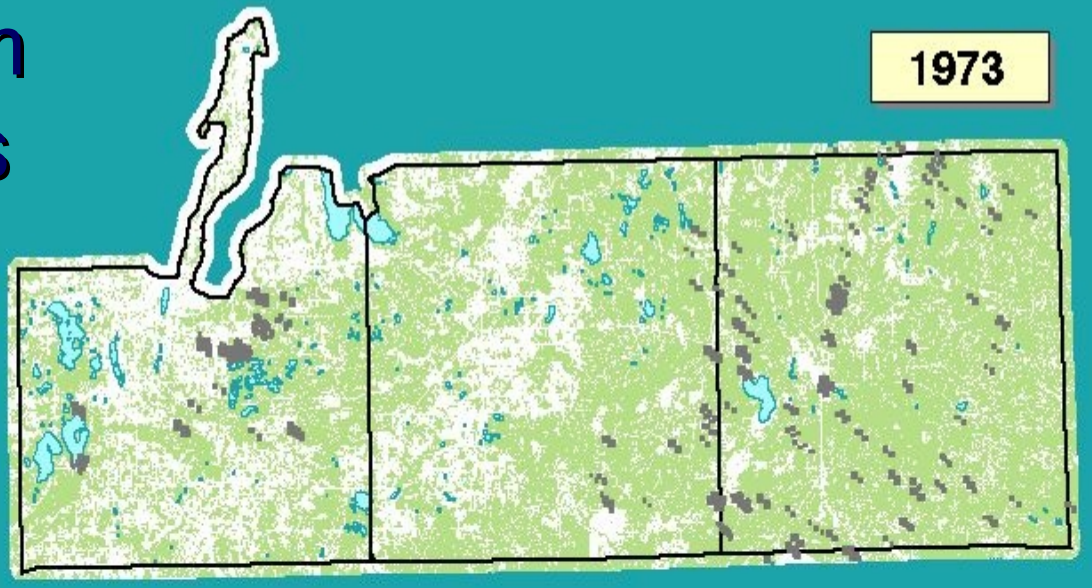
Parcel Size Average and Change by County Type



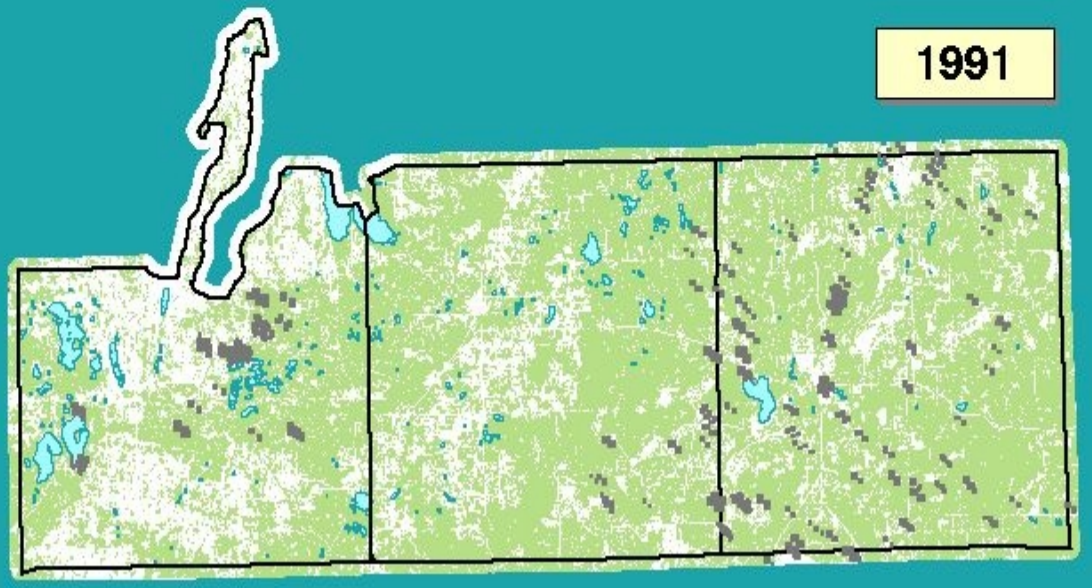


Forest Cover from NALC Composites

Pilot study area used for a student thesis. Forest fragmentation was compared with ownership parcelization at county, township (MCDs), and survey section scales.



Grand Traverse Kalkaska Crawford



Conclusions from Pilot Study II

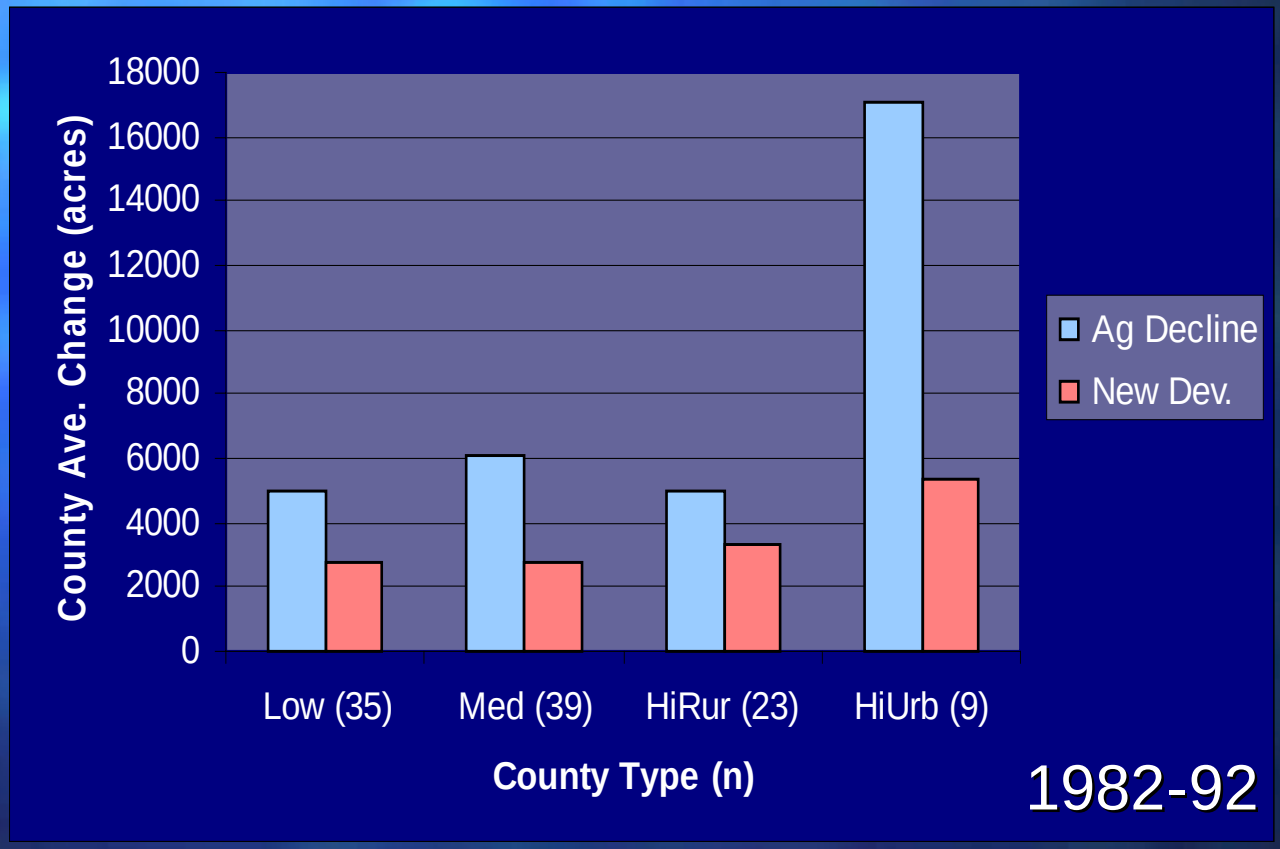
- Forest cover increased from 1973-91 and became less fragmented.
- Kalkaska County, with high population growth rate (156% over period) but low initial population (5272), experienced greatest forest regrowth (22.4%) and defragmentation (24%).
- Spatial patterns tend to be at scale of MCDs.
- Although consumption theory of land rent explains a good deal of variation in parcel sizes, relationship with forest cover is inconclusive.

Hypothesized Land Use Drivers

- Development of agricultural lands
  - Ag to developed, with some forest recovery
- Development of undeveloped lands
  - undeveloped (including forest) to developed
- Agricultural abandonment
  - Ag to undeveloped, usually with regrowth
- Recreation and tourism based development
  - any conversion to recreation-based use (includes seasonal homes)

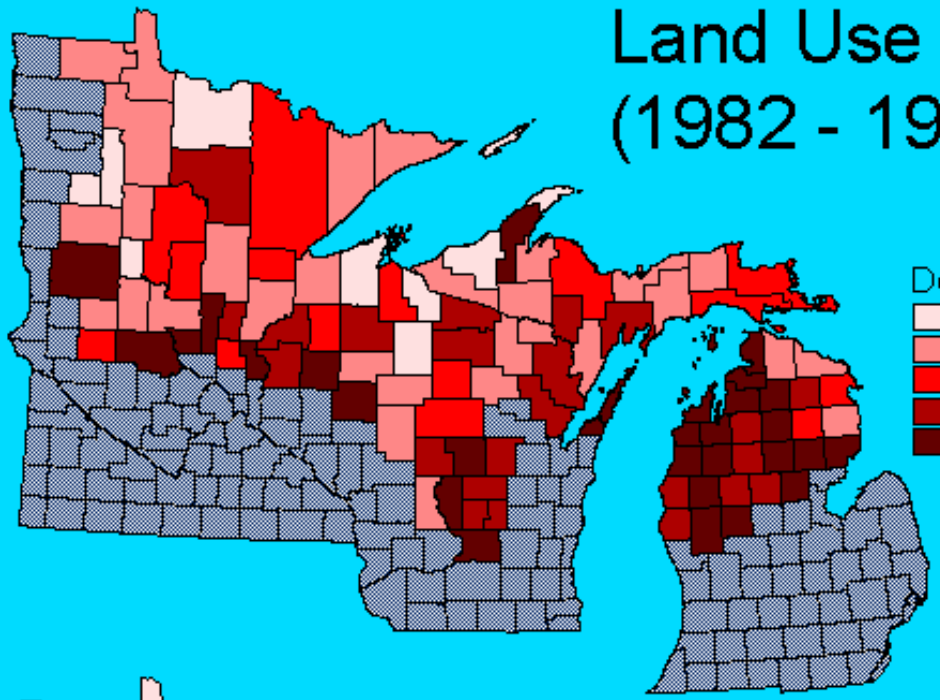

South Park Homes

Land Use Drivers in the Region

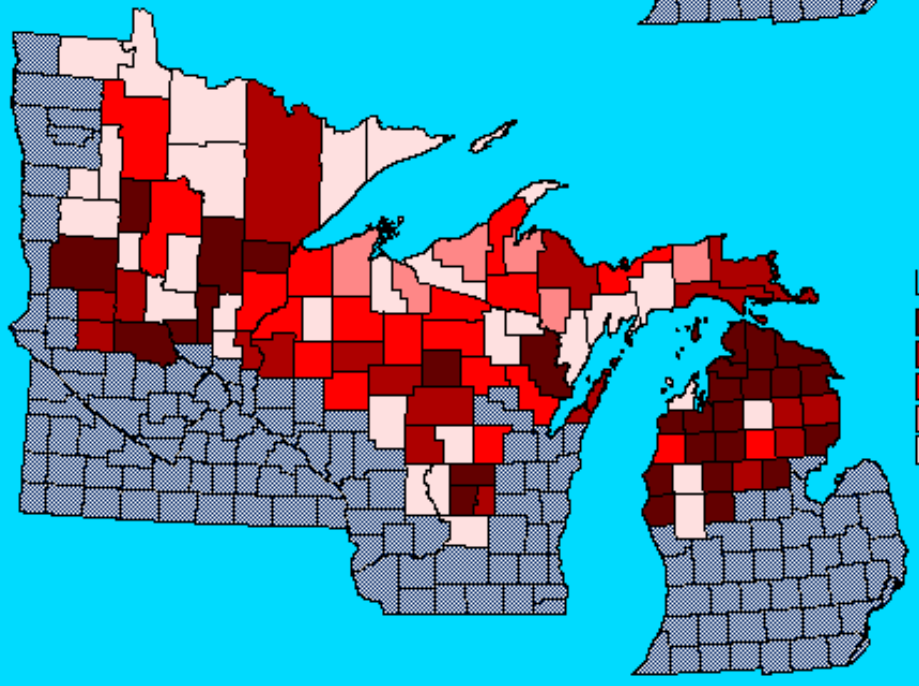


Source: Natural Resources Inventory (NRI), NRCS

Land Use Change (1982 - 1992; NRI)



Development (%)
- -0.15 - 0
- 0 - 0.31
- 0.31 - 0.42
- 0.42 - 0.82
- 0.82 - 3.24



Loss of Agricultural Land (%)
- -11.28 - -1.56
- -1.56 - -0.87
- -0.87 - -0.04
- -0.04 - 0
- 0 - 3.59

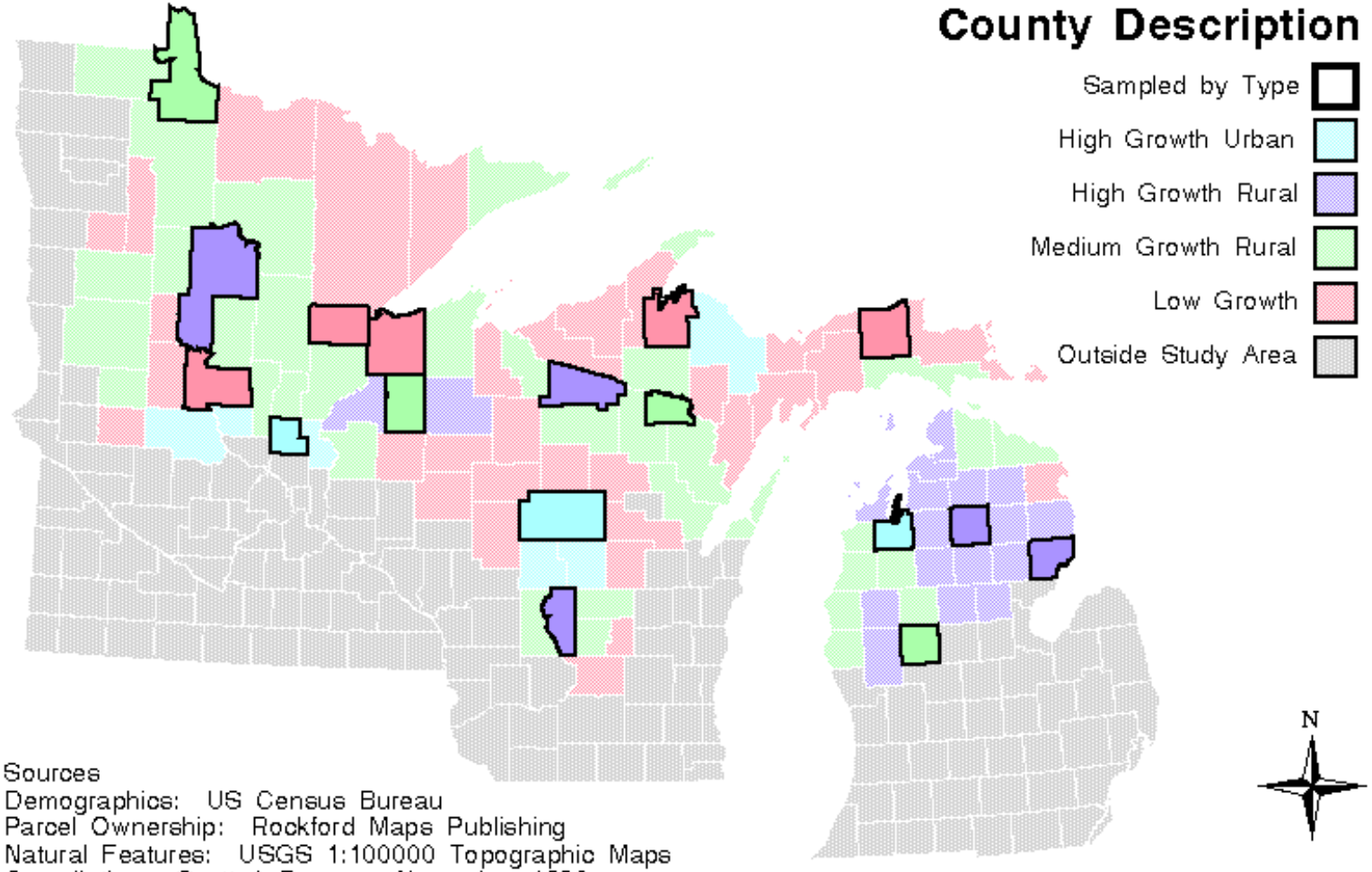
Air Photo Archive & Parcel Data

- 136 sample sites (~2500 ha) three epochs each (early 1970s, early 1980s, early 1990s)
- >1,200 archival photos scanned, rectified, mosaiced (2 m resolution)

- >10,000 polygons per epoch georeferenced & digitized from plat books.

Demographic / Economic County Types

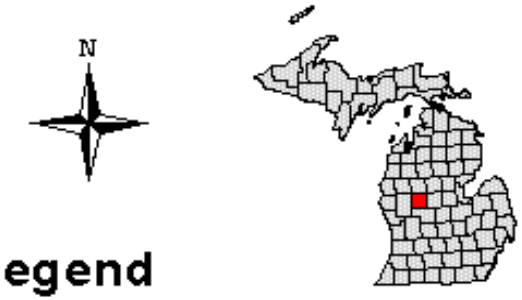
Area Frame Sampling



Sources
Demographics: US Census Bureau
Parcel Ownership: Rockford Maps Publishing
Natural Features: USGS 1:100000 Topographic Maps
Compilation: Scott A Drzyzga, November 1996

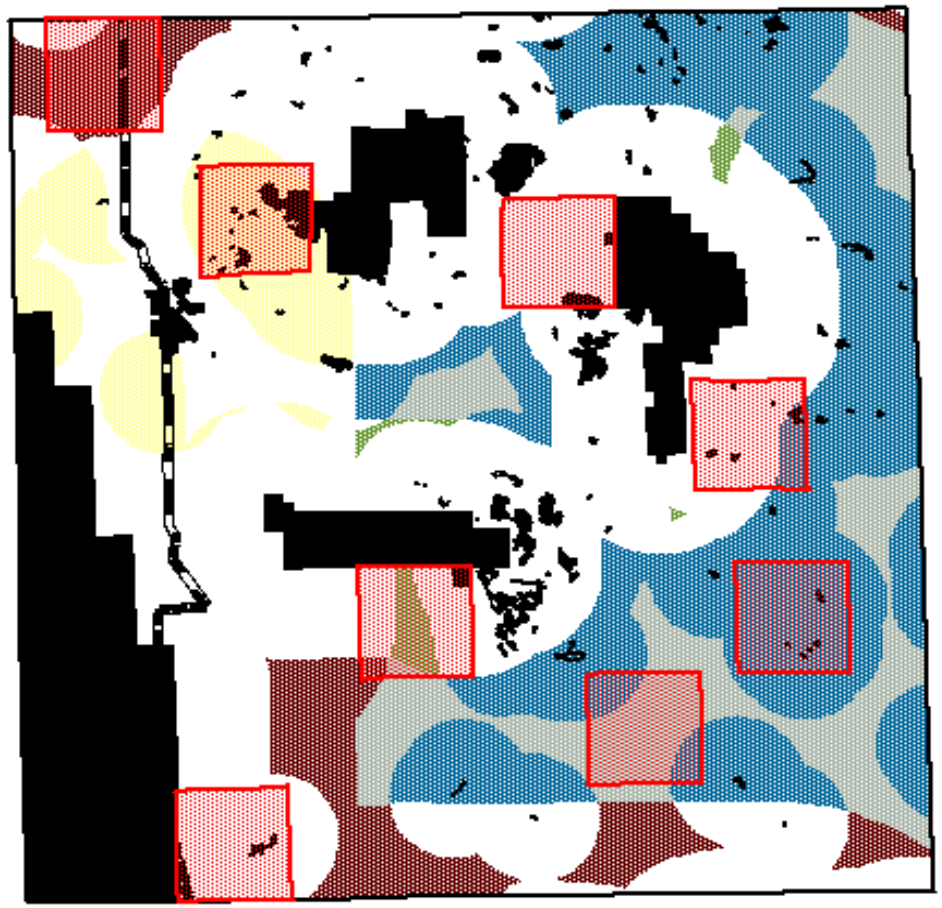
Stratified Sample Site Selection

Mecosta County Buffered Features



Legend

- Sample sites
- Buffered Features
- Under all influence
- Road-only influence
- Public land-only influence
- Hydro-only influence
- Under no influence
- Under multiple influence



Source: USGS 1:100000 Topographic Quad Maps

Compilation: Scott A Drzyzga 11/10/96

Land Use Classification

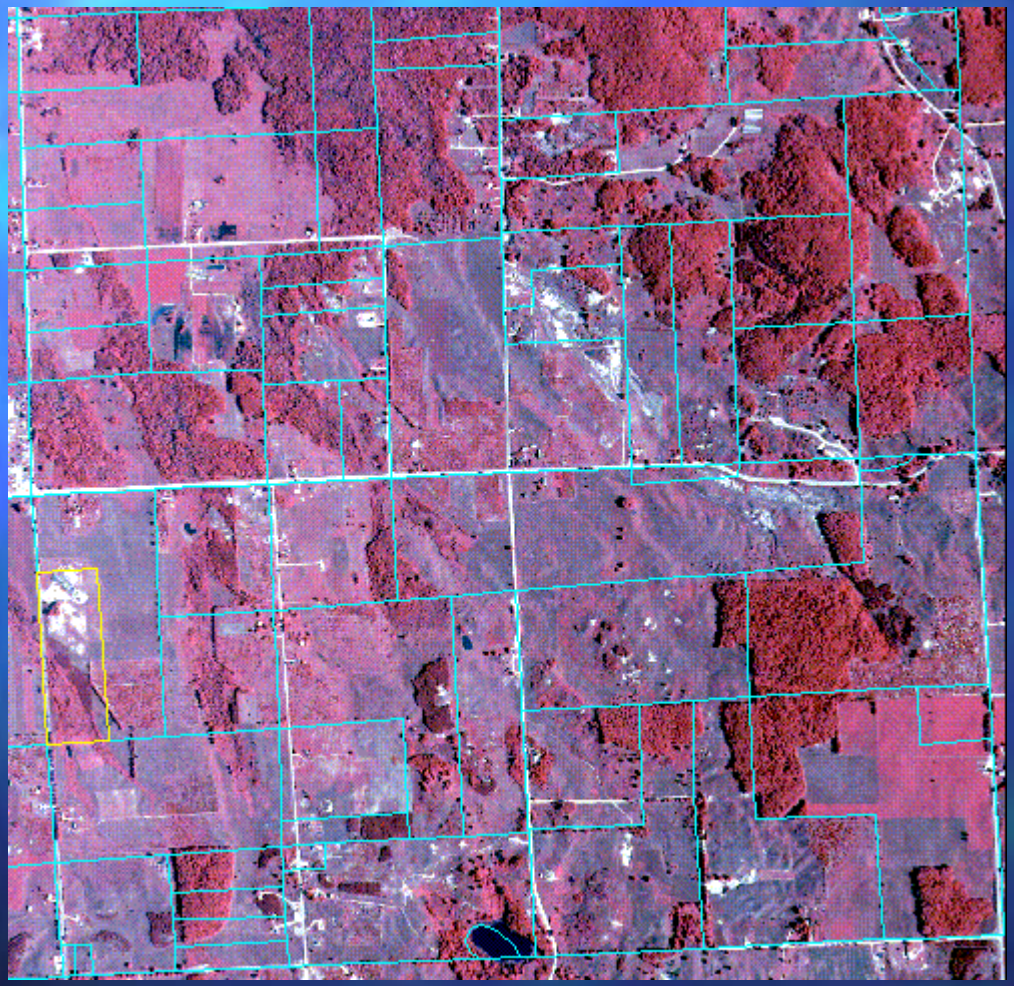
Students trained to identify classes using rules based on

- photo interpretation
- parcel size

Code	Land Use Type
100	**Developed**
110	Residential
111	High density Residential
112	Low density Residential
120	Retail/Office
130	Industrial/Warehouse
140	Infrastructure/Transportation
141	Airport
142	Transport Corridor or Terminal
143	Utility corridor or station
144	Institutional
150	Site-based outdoor recreation
151	Campground
152	Golf course
153	Ski area
154	Marina
155	Park and outdoor assembly
160	Mining/extractive
170	Other developed

200	**Agriculture**
210	Row crop
220	Non-row crop
230	Pasture/grazing
240	Other agriculture
300	**Undeveloped**
310	Open/grass
320	Old field/young forest
330	Mature Forest
340	Tree Plantation
350	Open Water
360	Wetland
370	Riparian Zone / Forested Wetland
380	Other Undeveloped

Land Use Patterns and Change

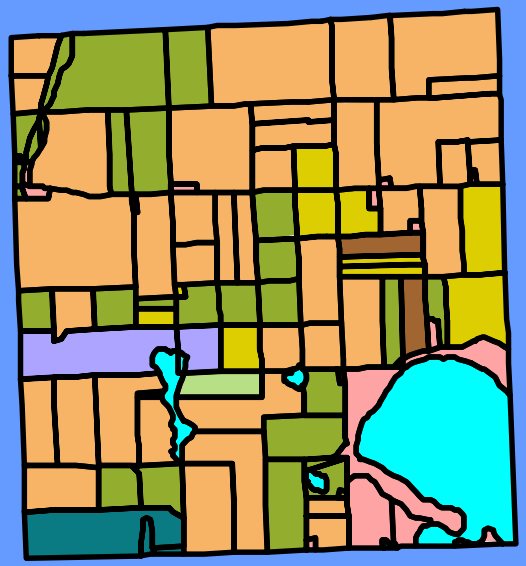


Digitized parcel map and aerial photography

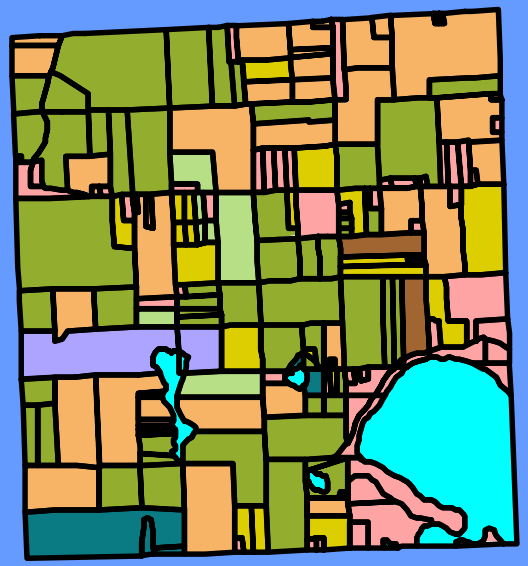
Interactive Land Use Classification System


CONSOLE
ARCEDIT
Pan/Zoom
x,y: 394443.67186,243641.65802
dx,dy: 2805.43379,-649.29262
dist: 2879.59019
1970
1980
1990
Transition
Three Classe
Oscillation
Missing Data
CLASSIFICATION
COVERAGE PUBLIC CONFIDENCE SECONDARY PRIMARY
COUNTY mecosta
EDIT COV 1990
1970 1980 1990
Area (ha) 24 15 14
Area (ac) 60 36 35
Primary LD Residential Pasture Row Crop
Percent PRI 40 70 40
Ownership Private Private Private
Confidence Above Avg High High
Secondary Retail/Office LD Residential LD Residential
Percent SEC 10 10 10
Public
Editphoto DATE 6/10/72 May-81 Jun-92
Editphoto TYPE B&W BCIR COLOR
REFRESH SCREEN
SAVE CHANGES
Edit PARCELS 1970 1980 1990
1970 Landuse LD Residential
1980 Landuse Pasture
1990 Landuse Row Crop
Site 1 2 3 4 5 6 7 8 CO
Show SHOW FLAGS SHOW PARCELS
Error Type Transition
Select Parcel * SELECT PARCEL *
LPQC - Quality Control
IMAGE_1970
Pan/Zoom
IMAGE_1980
Pan/Zoom
PARCELS_1990
Pan/Zoom
1970
1980
1990
Transition
Three Classes
Oscillation
Missing Data

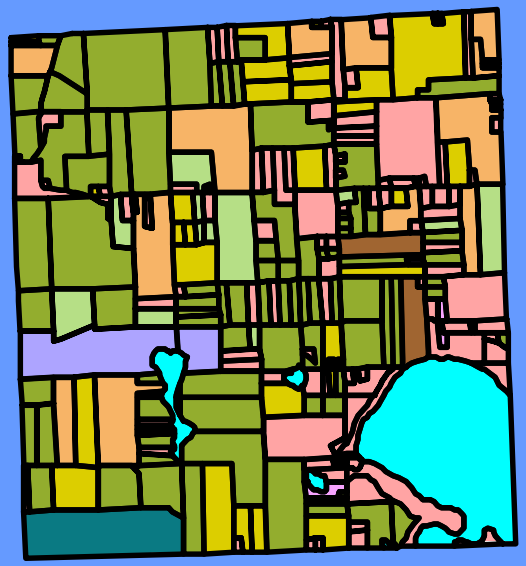
Interpreted Land Use



1973



1985

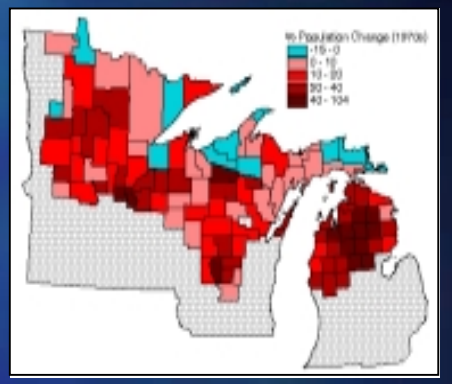


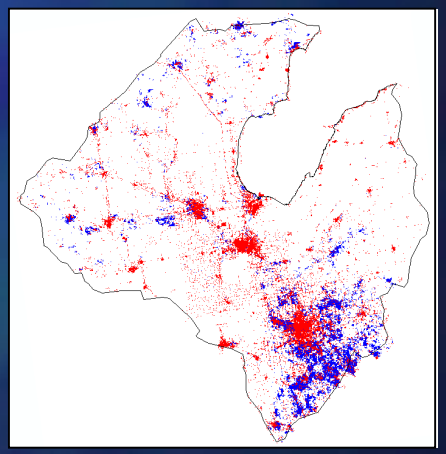
1991

- Unclassified
- Residential
- Commercial
- Trans/Utility
- Recreational
- Mining/Extract
- Other/Cemetery
- Agriculture
- Open/Grass
- Old Field/Yng Forest
- Forest
- Open Water
- Wetland
- Other Undev

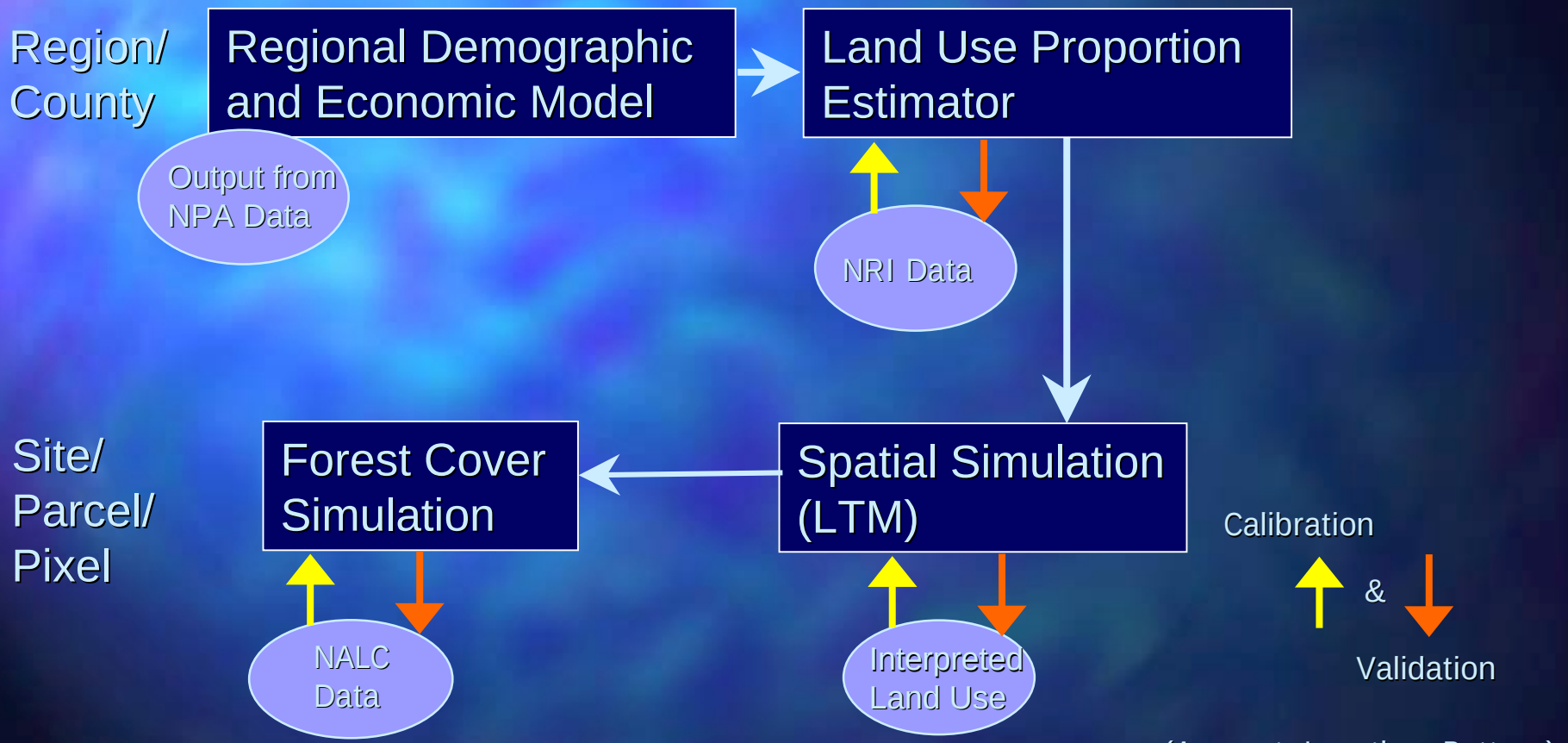
Approach to LCLUC Modeling

- Regional economic & demographic model produces county-level estimates.
  - statistically calibrated to project change in land use proportions using NRI data.
- GIS-based Land Transformation Model (LTM) used to spatially disaggregate and map LU changes.
- Probabilistic link between LU and forest cover change.





Modeling of LCLUC



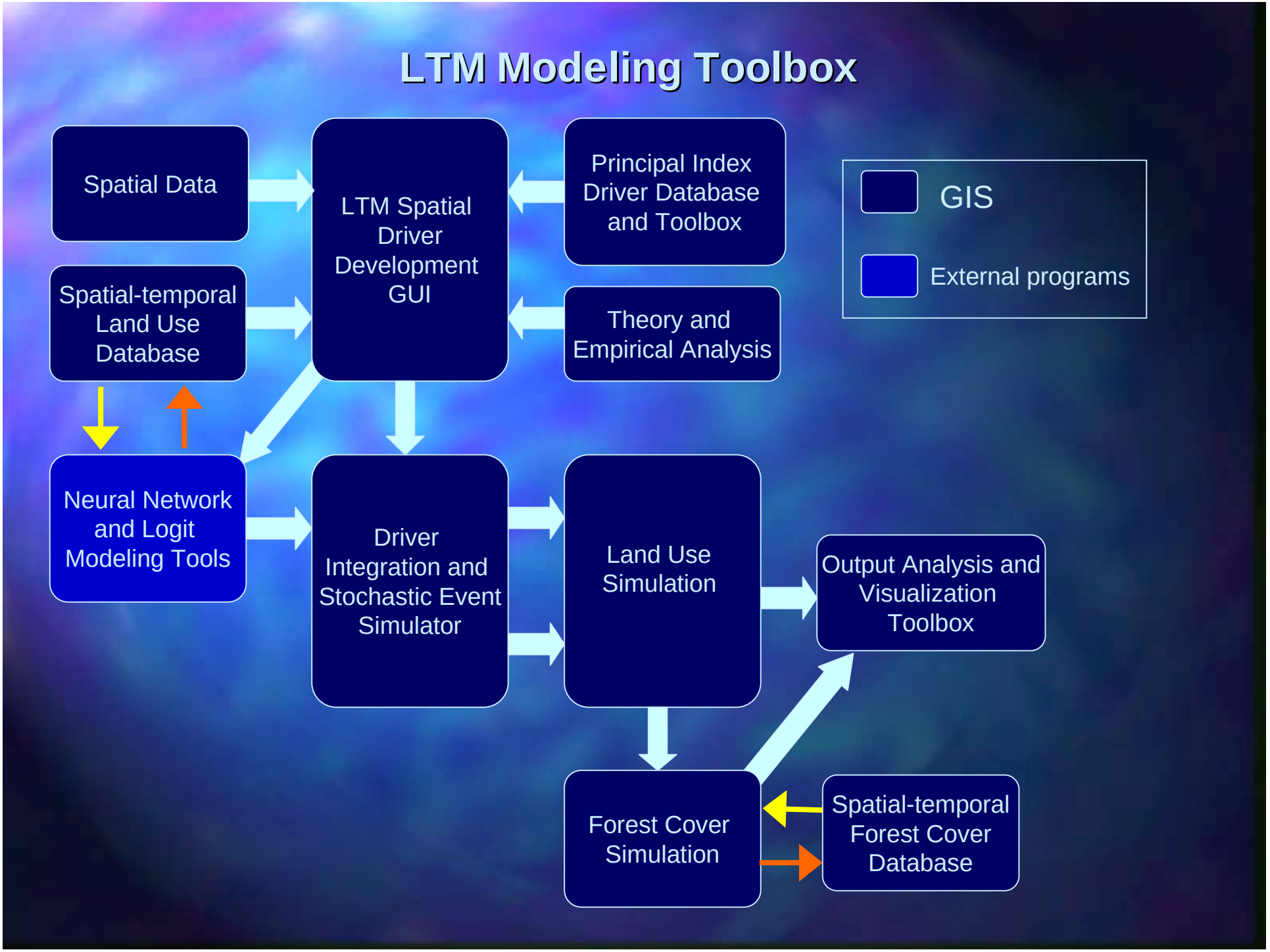
Land Use Proportion Estimates

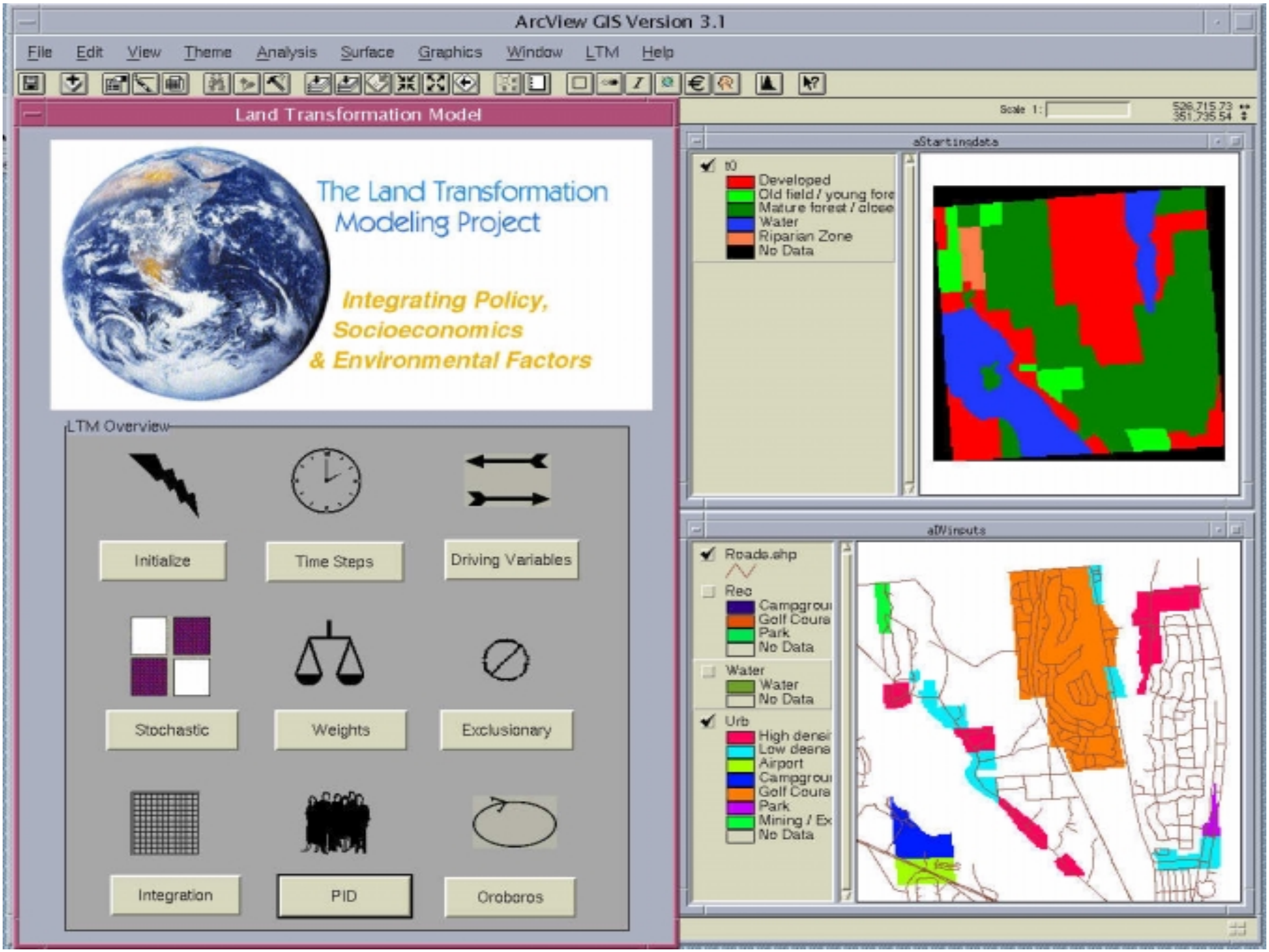
Change in land use proportion = f(

- change in population and number of households
- initial populations and numbers of households
- initial land use proportions
- change in employment and income by 1-digit SIC code
- average climate and soils
- change in population age structure
- state-level policy differences)

To be estimated using NRI data (1982, 1987, 1992) and socioeconomic data from NPA Data Associates (1967-2030).

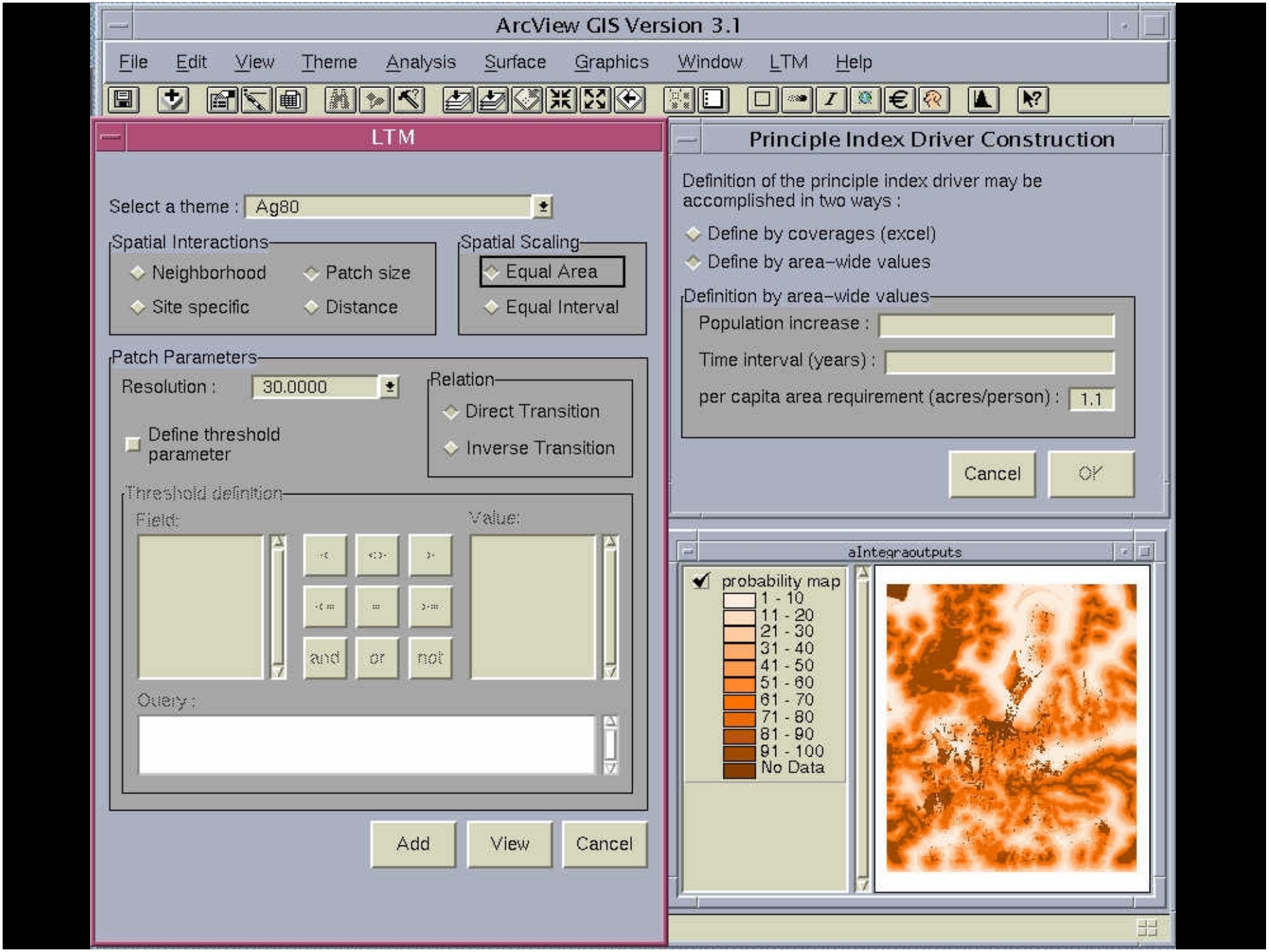
LTM Modeling Toolbox




ArcView GIS Version 3.1
File Edit View Theme Analysis Surface Graphics Window LTM Help
Land Transformation Model
The Land Transformation Modeling Project
Integrating Policy, Socioeconomics & Environmental Factors
LTM Overview
Initialize
Time Steps
Driving Variables
Stochastic
Weights
Exclusionary
Integration
PID
Oroboros
aStartingdata
t0
Developed
Old field / young fore
Mature forest / close
Water
Riparian Zone
No Data
aDVinputs
Roads.shp
Rec
Campgrou
Golf Cours
Park
No Data
Water
Water
No Data
Urb
High densi
Low dens
Airport
Campgrou
Golf Cours
Park
Mining / Ex
No Data

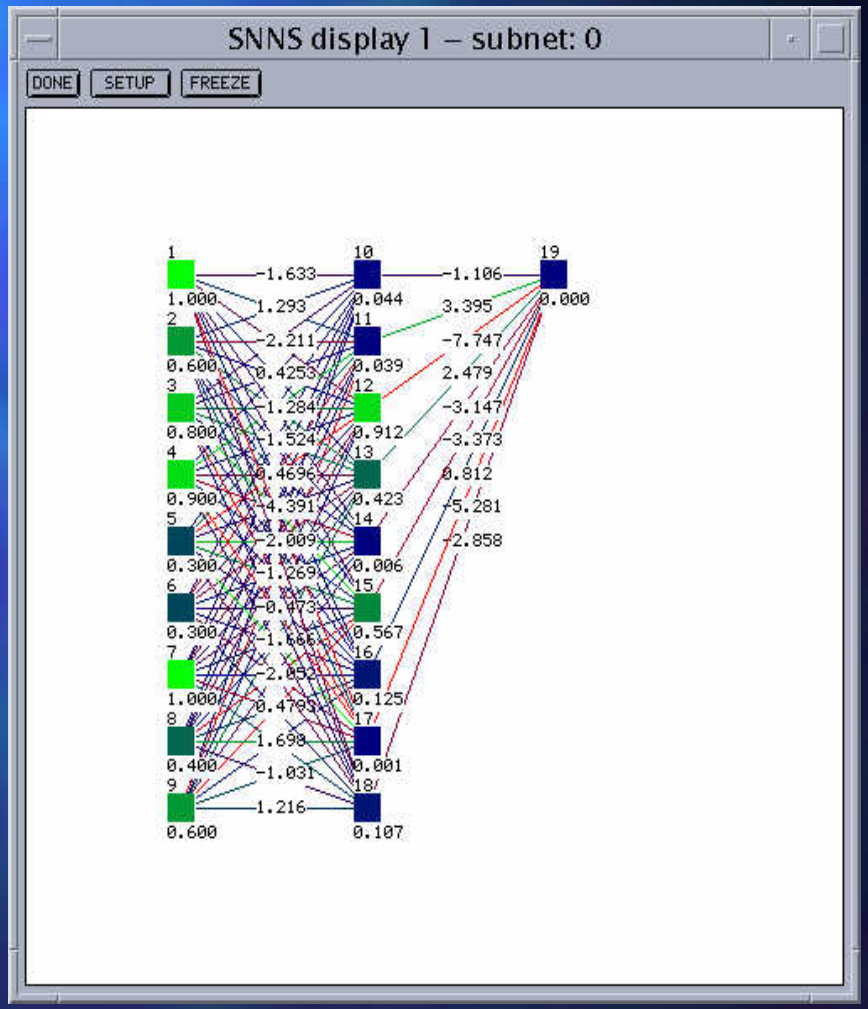
Spatial Variables

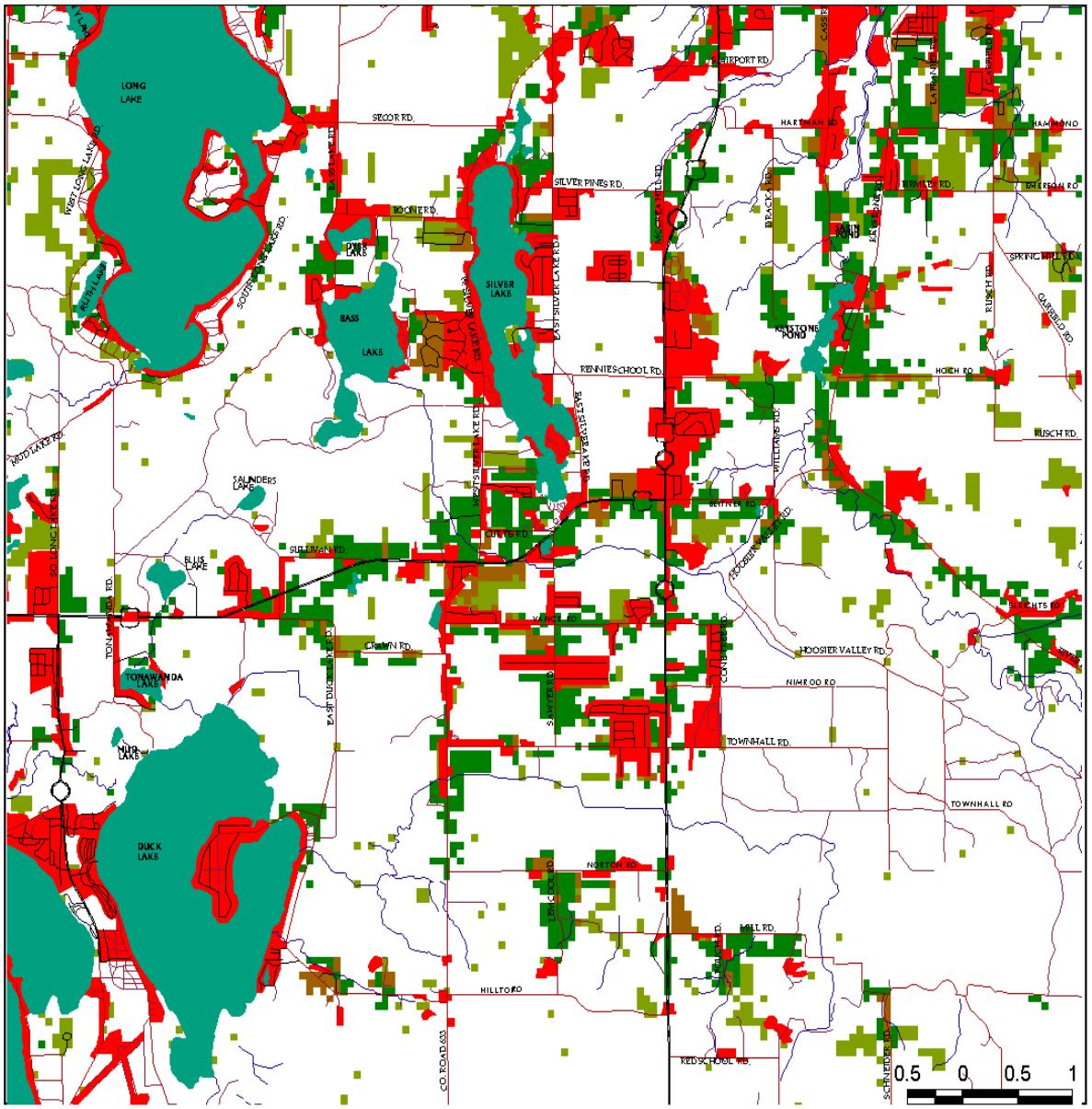
- soils
- terrain
- waterfronts (lakes and rivers) and views
- surrounding land use and existing urban
- roads
- parcel sizes
- public land ownership (constraint)


ArcView GIS Version 3.1
File Edit View Theme Analysis Surface Graphics Window LTM Help
LTM
Select a theme : Ag80
Spatial Interactions
Neighborhood
Patch size
Site specific
Distance
Spatial Scaling
Equal Area
Equal Interval
Patch Parameters
Resolution : 30.0000
Define threshold parameter
Relation
Direct Transition
Inverse Transition
Threshold definition
Field:
Value:
and
or
not
Query :
Add
View
Cancel
Principle Index Driver Construction
Definition of the principle index driver may be accomplished in two ways :
Define by coverages (excel)
Define by area-wide values
Definition by area-wide values
Population increase :
Time interval (years) :
per capita area requirement (acres/person) : 1.1
Cancel
OK
aIntegraoutputs
probability map
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
No Data

Artificial Neural Net (ANN) Modeling

- Use ANN to learn how factors influenced historical land use change
- Software link written between LTM in ArcView and SNNS neural net software.
- Drivers include: prior land use, roads, distance to urban, prob. of farm closure, infrastructure, surrounding land use.



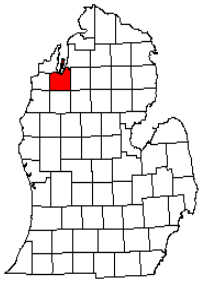


Predicted and Not Predicted

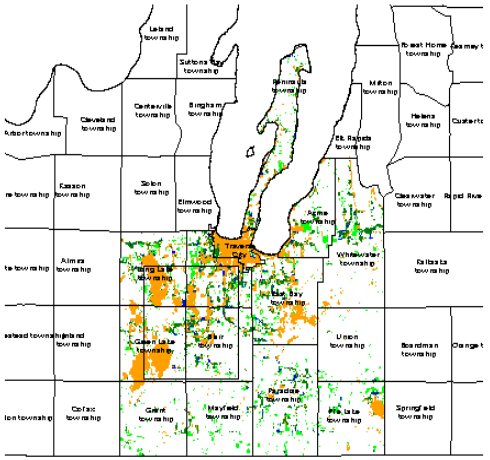
County Roads
Highways
Streets
Rivers
Lakes

urban Land Use 1980
non-urban

Changemap
not transitioned and not predic
transitioned, not predicted
not transitioned but predicted
transitioned and predicted
No Data



N



Methodological Contributions to Date

- Procedures and tool development for land use change mapping.
- Error estimation in quantifying forest cover change and fragmentation.
- Incorporation of neural network estimation, stochastic events, and dynamics into a nested version of GIS-based Land Transformation Model.

Possible Policy Implications

- Current patterns and trends in forest cover and pattern change tend to be positive (says nothing of forest characteristics).
- Development has not yet had a significant negative influence on forest cover, but ag. abandonment has had a positive influence.
- Ownership fragmentation increases complexity of management and likelihood of land use conflict.
- Agriculture is interrelated with forest regrowth and carbon sequestration. We need a good model of agricultural abandonment.

Outreach

- USGCRP National Assessment
  - Land use/cover change is often not included in assessments of system response to climate change (e.g., VEMAP I). Data and models will help.
- Upper Great Lakes RESAC
  - Output from project supports delivery of land use/cover change tools and data to agency-based stakeholders (DNRs, USFS, USGS, NRCS).

Project Timeline

Tasks	1997	1998	1999	2000
Air Photo Interpretation				
NALC Pre-Processing				
NALC Classification				
Accuracy Assessment and Mosaicking				
Empirical Analyses				
LTM Modification and Testing				
Reports and Papers